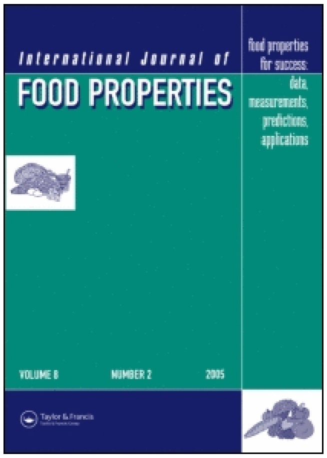

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VERTICAL AIRFLOW RESISTANCE OF CHICKPEA (*C. arietinum*) CULTIVARS AS AFFECTED BY BULK DENSITY AND MOISTURE CONTENT

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Resistances of three chickpea cultivars (large kabuli, small kabuli, and desi) to airflow ranging from 0.02 to 0.4 $m^3s^{-1}m^{-2}$ were measured in vertical direction at three levels of bulk density and three levels of moisture content. The effects of moisture content, bulk density, and bed depth on airflow resistance of chickpea were investigated. Pressure drop increased with airflow rate and bulk density but decreased with increasing moisture content. Airflow resistance per unit depth of seed column increased linearly with bed depth. Three models (Shedd, Hukill and Ives, and Ergun) were fitted to the experimental data by using PROC NLIN of the SAS software. The percentage relative error approached zero for airflow rates of more than 0.1 $m^3s^{-1}m^{-2}$. The coefficient of multiple determination (R^2), and the mean square error (MSE) of predicted values with respect to the measured values for various chickpea samples were used to evaluate the models. The values of coefficient of determination were greater than 0.90 in all experimental trials indicating good fit of the models.

Keywords: ***Bulk density, Particle density, Physical attributes, Kabuli, Desi.***

INTRODUCTION

Chickpea (*Cicer arietinum*), an important source of protein and starch is grown as specialty crop in Saskatchewan and Canada; is exported around the world. According to Saskatchewan Agriculture, Food and Rural Revitalization,[1] chickpea production in Saskatchewan was 446,800 tonnes in 2001, while world production was 6,063,000 tonnes in the same period.[2] There are two main types of chickpea, namely desi and kabuli. The desi type (Indian origin) has a thick, colored seed coat; while the kabuli type (Mediterranean and Middle Eastern origin) has a thin, white seed coat. The kabuli type is larger than the desi type and is preferred by consumers.[3]

Reducing the temperature and moisture content of agricultural products during storage is necessary to avoid microbial and insect growth. In storage bins, an aeration system may be used to maintain products at sufficiently low temperature.[4] Knowledge of airflow resistance is an important consideration in designing an appropriate drying and aeration

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system. The resistance to airflow of grains and seeds is represented by pressure drops across unit depths of column of products which is affected by moisture content, compaction of material, and fines concentration.[5]

Several equations have been suggested by researchers to show the relationship between pressure drop and airflow rate. The most commonly used model was proposed by Shedd,[6] which is represented by the following:

$$\frac{\Delta P}{L} = A(Q)^{B}, \quad (1)$$

where Q is airflow rate ($m^3s^{-1}m^{-2}$); $\Delta P/L$ is pressure drop per unit depth (Pa/m); and A and B are experimentally determined constants. Hukill and Ives,[7] proposed the following empirical equation:

$$\frac{\Delta P}{L} = \frac{CQ^2}{Ln(1+DQ)}, \quad (2)$$

where C and D are constants for a particular grain. Equation 2 is applicable over a wide airflow range of 0.01 to 2.0 ($m^3s^{-1}m^{-2}$).[8] Ergun[9] proposed a second-order polynomial model which was modified by Hunter[10] and Bakker-Arkema et al.,[11] and is represented by the following:

$$\frac{\Delta P}{L} = EQ + FQ^2, \quad (3)$$

where E and F are experimentally determined constants, which include the effect of fluid properties. Since airflow resistance of materials is affected by moisture content, bulk density, and percentage of fines, some researchers have used the standard stepwise non-linear regression techniques to express the relationship between airflow resistance and the experimental variables.[5] The airflow resistance for most agricultural products in the vertical airflow direction is published as ASAE standard D272.2.[12] Direction of airflow was investigated by some researchers. Kay et al.[13] showed that shelled corn had greater airflow resistance in the vertical direction than in the horizontal direction.

The objectives of this study were to: measure the vertical airflow resistance of three chickpea cultivars (large kabuli, small kabuli and desi) at three levels of moisture content and bulk density; fit the three airflow resistance models [Eqs. (1, 2, 3)] to the experimental data; and evaluate the fitted models by comparing the predicted and experimental values of pressure drop for each chickpea sample at three levels of moisture content and three levels of bulk densities.

MATERIALS AND METHODS

Materials

Dry chickpea (large and small kabuli and desi) seed samples were procured from Canadian Select Grains Ltd. of Eston, SK, Canada. The seeds were kept in cold storage at 5°C for a few months. The moisture content of the samples was determined by drying triplicate samples of about 2 to 3 g ground chickpea for 60 min in an air convection oven at 130 ± 1°C.[14] All moisture contents are reported in percent wet basis.

Sample Preparation

The chickpea seed samples with higher moisture contents were prepared by adding calculated amounts of distilled water. In order to allow the moisture to distribute uniformly throughout the seeds, a concrete mixer was used to mix the samples during wetting. To obtain high moisture samples and to ensure uniform water adsorption, samples were moistened in two stages within 3 h.[4] The samples were then sealed in separate polyethylene bags and stored in cold storage at 5°C for a minimum of 5 days. Before the start of each test, the required amount of seed was allowed to warm up to room temperature (approximately 22°C) for 24 h in separate pouches.[8]

Physical Attributes

The dimensions, particle density, and bulk density of chickpea seed samples were measured. One hundred fifty seeds of each chickpea cultivar were randomly selected from the bulk sample with three initial moistures. To determine the size and shape of sampled chickpea seeds, the length and width of the seeds were measured using a computer imaging system, while the third dimension was measured by using a digital caliper.[15] The imaging system consisted of a Sony DXC-151A CCD color video camera (Sony Corporation, Japan), light stand, Matrox Meteor RGB capture card, Pentium III 700 personal computer, and Matrox Inspector version 2.1 (Matrox Electronic Systems Ltd, Dorval, QC, Canada) software. In order to increase the measurement accuracy of seed size and shape, significant contrast between the seed and the background was required. This was obtained by using a black sheet under the seed as background and the lights, camera height, brightness, zoom, and focus were adjusted. Each chickpea seed was individually placed on a black sheet in its natural position with its length parallel to the y-coordinate. Features of each seed image including area, feret x, feret y (the dimensions of the minimum bounding box on a seed image in the horizontal and vertical direction, respectively) were determined and saved in MS Excel workbook format for further analysis. Ferets y and x of each seed were reported as major and intermediate dimensions (mm), respectively.

Particle density, bulk density, and porosity: Particle density is defined as the ratio of the mass of the seeds in air to their volume.[16] The gas comparison multipycnometer (Quanta Chrome Corporation, Boynton Beach, FL) using nitrogen gas was used to measure volume of the seed samples. The mass of seed samples was measured by using an electronic weighing balance (Ohaus Scale Corp. G 160D, Germany) reading to 0.0001 g. The average value of the densities was taken from three replications at initial moisture content for each chickpea cultivar. Bulk density was calculated from the mass of the 0.5 L steel cup that was filled with chickpea seeds.[17] The seeds were dropped from a funnel which had an opening of 31.8 mm. The bottom of the funnel was 51.75 mm above the cup. The excess seeds were removed by passing a wooden stick across the top surface using 5 zigzag motions.[18,20] The void space between seeds or inter-particle porosity (ε) expressed in percent was calculated from bulk and particle densities using the following relationship.[21]

$$\varepsilon = \frac{\rho_p - \rho_b}{\rho_p}, \tag{4}$$

where ρ_b is the bulk density (kg/m^3) and ρ_p is the particle density (kg/m^3). The relationship between airflow resistance and experimental variables using standard stepwise regression has been reported by Siebenmorgen and Jindal[5] on rough rice and Dairo and Ajibola[8] on sesame seed. The equation developed was generally of the form:

$$\Delta P = aQ^2 + bMQ + c\rho_b Q + dFQ, \tag{5}$$

where ΔP is the pressure drop (Pa/m); Q is the airflow rate ($m^3s^{-1}m^{-2}$); M is the moisture content (% wet basis); ρ_b is the bulk density (kg/m^3); F is the percentage of fines (%); and a, b, c, and d are model constants.

Airflow Test Apparatus

A schematic diagram of the apparatus used for airflow resistance measurement is shown in Fig. 1. It consists of a variable speed fan, duct, two sets of straighteners arranged in series, test column, manometer and air velocity meter. An airflow resistance apparatus should have a test column diameter of at least 20 times that of the particle diameter.[4] The test column was made of flanged sections of 300 mm internal diameter Plexiglas tube and 3 mm thick, joined together to provide a 1.3 m long column. A 2 mm thick stainless steel screen with a nominal opening of 5 mm was used as floor for the test column. The screen was sandwiched between the two acrylic rings and fastened together by bolts and sealed by fast glue.

The test column was bolted to a cylindrical steel plenum with a diameter of 400 mm and a length of 700 mm. To provide uniform air distribution in the duct and the test

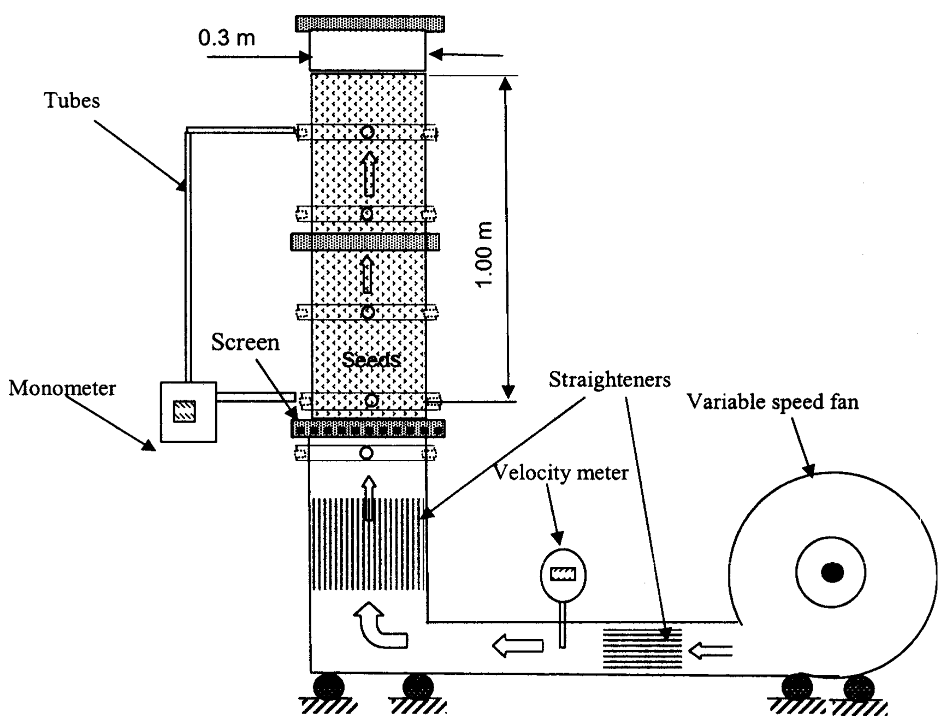

Figure 1 Schematic diagram of apparatus for measuring the airflow resistance of seeds.

column containing the sample, two sets of air straighteners were installed in series: one, before the air velocity meter; and the other, before the test column. The straighteners were plastic drinking straws 150 mm long and 2 mm internal diameter. To cover the total airflow range, two variable speed centrifugal fans and an inverter-type motor speed control were used. A one-phase centrifugal fan (0.2 kW, 1550 rpm) was used to provide airflow rates between 0.02 and 0.1 $m^3s^{-1}m^{-2}$. For airflow rates between 0.1 and 0.4 $m^3s^{-1}m^{-2}$, a three-phase centrifugal fan (3.75 kW, 1750 rpm) was used. Airflow rates were measured by using an electronic air velocity meter (Model No. 8382-E-GB, TSI Inc., St. Paul, MN) reading to 0.001 m/s; this was located in the duct 100 mm after the straightener.

Pressure drops were measured in four levels across a 1 m depth of test column filled with sample. The pressure taps were located at 0.25, 0.50, 0.75, and 1 m from the top of the seed level. Each level had four horizontal taps threaded 90° apart into the side of the test column and flush with the side of the container. In each level, the taps were joined together with 4 mm diameter tubes. An electronic manometer reading to 0.25 Pa (0.001 in. H_2O) was used to measure the pressure drops. Under 5 kPa pressure, the system was tested for leakage by using soap solution; no leakage was detected.

Experimental Design

The experimental trials involved combinations of three moisture levels and three bulk densities for three chickpea cultivars (large kabuli, small kabuli and desi). Some researchers reported that pressure drop linearly change with bed depth.[8, 22] In this study, pressure drop was measured at depths of 25, 50, 75 and 100 cm from the top of the seed column. The first tap above the screen floor of the test column was chosen as the reference. The pressure differences between the first tap and all the other taps were measured and recorded. The airflow rates used were 0.02, 0.04, 0.08, 0.1, 0.2, 0.3, and 0.4 $m^3s^{-1}m^{-2}$.

A funnel was used to fill the seed column. To obtain low bulk density, no compaction was done on the seed samples in the column. Medium and high bulk densities were obtained by using a 5 kg steel disk weight during filling of the seeds in layers. The weight was released freely 10 times from a height of 20 cm above the seed layer. To obtain medium and high density packing, each seed layer was 33 and 20 cm high, respectively; filling was done until the test column was 1 m high. The total weight of filled seeds was divided by the volume occupied by the seed column yielding the bulk density of the seed samples. The volume of the seed column was calculated by measuring the height and the diameter of the container filled with the seed samples. After each experiment, the test column was emptied by a vacuum cleaner, then the test column was refilled and measurements were repeated to obtain three replications.

Equations 1, 2, and 3 were fitted to the experimental data at each moisture level by using the NLIN procedure of SAS[23] and the parameters in each equation were estimated. To evaluate the fit of the models, the REG procedure of SAS was used to obtain the coefficient of multiple determination (R^2) and the mean square error (MSE) of predicted values with respect to the measured values.

RESULTS AND DISCUSSION

Physical Attributes of Chickpea Seed

Table 1 shows the dimensions, particle density, bulk density and the calculated porosity of the three chickpea cultivars at initial moisture content. The values of dimensions

Table 1 Physical attributes of three chickpea cultivars measured at initial moisture content.

Type	Moisture content (% w.b.)	Dimensions† (mm)			Particle density‡ (kg/m³)	Bulk density‡ (kg/m³)	Porosity‡ (%)
		Major	Intermediate	Minor			
Large kabuli	8.91	10.42 (0.04)*	8.35 (0.03)	8.25 (0.03)	1473 (9.5)	808 (1.92)	43.79 (0.35)
Small kabuli (chico)	9.32	8.53 (0.05)	7.06 (0.03)	6.81 (0.03)	1422.8 (6.6)	823.31 (2.37)	42.13 (0.11)
Desi	9.21	8.08 (0.05)	6.46 (0.04)	5.89 (0.11)	1394.9 (3.3)	780.74 (3.38)	44.03 (0.33)

*Standard deviation; †N = 150; and ‡N = 3.

for large kabuli and desi chickpea were the highest and the lowest, respectively. Minimum and maximum values of bulk density were 780.74 and 823.31 kg/m^3 for desi and small kabuli chickpea, respectively. The bulk density was affected by packing of the bed. Table 2 shows that bulk density of chickpea decreased with increasing moisture content. Monirul Islam Chowdhury et al.[19] reported similar result for gram. Table 2 shows that bulk density increased with the degree of packing. Similar observations were made by Siebenmorgen and Jindal[5] on rough rice and Dairo and Ajibola[8] on sesame seed.

Airflow Resistance of Chickpea

The pressure drop per unit depth for the three chickpea cultivars at three levels of moisture content and bulk density are shown in Table 2. The values of moisture content represent an average of three replications. At each moisture level, the pressure drop increased with airflow rate and at each airflow rate, the pressure drop decreased with increasing moisture content. Sokhansanj et al.[24] and Jayas et al.[22] reported similar results for lentils and canola, respectively.

At each moisture level, three levels of bulk densities were obtained by using different methods of filling or packing. ρ_{b1}, ρ_{b2} and ρ_{b3} are the bulk density values at low, medium and high degrees of packing, respectively. The experimental data revealed that pressure drop generally increased with increasing bulk density (Table 2). A similar trend was reported by Yang and Williams[25] for grain sorghum and Li and Sokhansanj[26] for alfalfa seeds.

Table 2 also shows that the magnitude of airflow resistance in desi chickpea was the highest among the three chickpea cultivars at the same moisture and bulk density levels. The corresponding value for large kabuli chickpea was the lowest. Figure 2 shows the typical effect of bed depth on airflow resistance of chickpea. Pressure drop per unit depth of seed column, increased linearly with bed depth. The same behavior was observed for both small kabuli and desi chickpeas. This is similar to the observation of Dairo and Ajibola[8] for sesame seed and Jayas et al.[22] for canola.

Fitting Models to Airflow Resistance Data

The three models (Shedd, Hukill and Ives, and Ergun) were fitted to the experimental data at each moisture level and bulk density. The estimated parameters, coefficient of multiple determination (R^2), and the mean square error (MSE) of predicted values with respect to measured values for various chickpea samples are shown in Tables 3, 4 and 5.

Table 2 Experimental data of airflow resistance (Pa/m) of three chickpea cultivars as affected by moisture content, bulk density and airflow rate.*

		Moisture content†								
		M_1			M_2			M_3		
		Bulk density (ρ_b) (kg/m^3)								
Cultivar	Airflow rate ($m^3s^{-1}m^{-2}$)	ρ_{b1} = 770	ρ_{b2} = 827.3	ρ_{b3} = 837.9	ρ_{b1} = 764.3	ρ_{b2} = 821	ρ_{b3} = 831.6	ρ_{b1} = 738.9	ρ_{b2} = 778.5	ρ_{b3} = 809.6
Large kabuli	0.02	4.5	4.8	4.9	4.0	4.2	6.1	3.4	4.01	6.0
	0.04	11.1	11.2	11.3	7.0	10.2	11.2	6.1	9.0	10.9
	0.08	21.9	31.1	32.3	19.6	28.8	30.8	14.3	20.6	28.0
	0.1	37.4	41.4	44.1	27.1	32.6	42.8	22.2	30.4	40.2
	0.2	125.0	129.1	140.6	84.4	118.5	135.9	84.2	101.9	113.2
	0.3	226.9	262.5	275.2	162.3	233.3	250.6	161.5	194.8	244.6
	0.4	369.7	410.6	491.6	273.3	327.5	381.3	244.8	299.5	373.6
		ρ_{b1} = 806.8	ρ_{b2} = 841.5	ρ_{b3} = 863.4	ρ_{b1} = 785.6	ρ_{b2} = 819.5	ρ_{b3} = 840.8	ρ_{b1} = 753	ρ_{b2} = 788.4	ρ_{b3} = 815.3
Small abuli (chico)	0.02	8.1	8.6	9.3	5.3	6.1	7.4	3.5	5.8	6.6
	0.04	17.1	17.2	18.7	10.8	13.3	15.6	7.6	12.1	14.5
	0.08	40.3	42.8	45.9	23.0	23.2	31.6	18.8	20.9	30.0
	0.1	51.9	52.8	59.7	37.2	47.8	49.7	29.0	43.5	48.1
	0.2	161.8	163.0	176.5	117.9	141.1	161.7	106.4	137.8	149.8
	0.3	306.4	309.0	312.7	210.1	249.9	267.5	181.3	210.1	250.1
	0.4	515.6	430.0	473.4	351.0	401.6	438.1	306.0	370.4	402.2
		ρ_{b1} = 754.4	ρ_{b2} = 792.6	ρ_{b3} = 809.6	ρ_{b1} = 720.5	ρ_{b2} = 756.6	ρ_{b3} = 772.9	ρ_{b1} = 693.6	ρ_{b2} = 741.7	ρ_{b3} = 760.8
Desi	0.02	8.9	9.0	10.3	5.5	6.3	6.8	3.9	5.8	6.2
	0.04	15.5	16.4	16.8	10.5	16.1	16.1	8.7	14.9	15.7
	0.08	31.9	38.5	53.3	25.0	38.2	47.0	24.0	37.3	43.3
	0.1	48.8	62.6	67.0	39.3	49.3	61.1	35.4	48.8	56.7
	0.2	162.2	174.0	179.4	112.5	124.3	156.6	109.5	114.4	137.8
	0.3	325.9	342.0	362.3	269.9	279.5	334.0	199.7	261.5	325.4
	0.4	467.3	487.1	550.7	317.4	390.9	496.8	351.0	370.0	447.9

*Each value represents an average of three replicates. †M_1: 9.32, 9.82, 9.56 (% w.b.) for large kabuli, small kabuli and desi, respectively. M_2: 12.72, 15.1, 13.83 (% w.b.) for large kabuli, small kabuli and desi, respectively M_3: 16.1, 18.2, 17.15 (% w.b.) for large kabuli, small kabuli and desi, respectively. ρ_{b1}, ρ_{b2}, ρ_{b3}: low, medium and high bulk density, respectively.

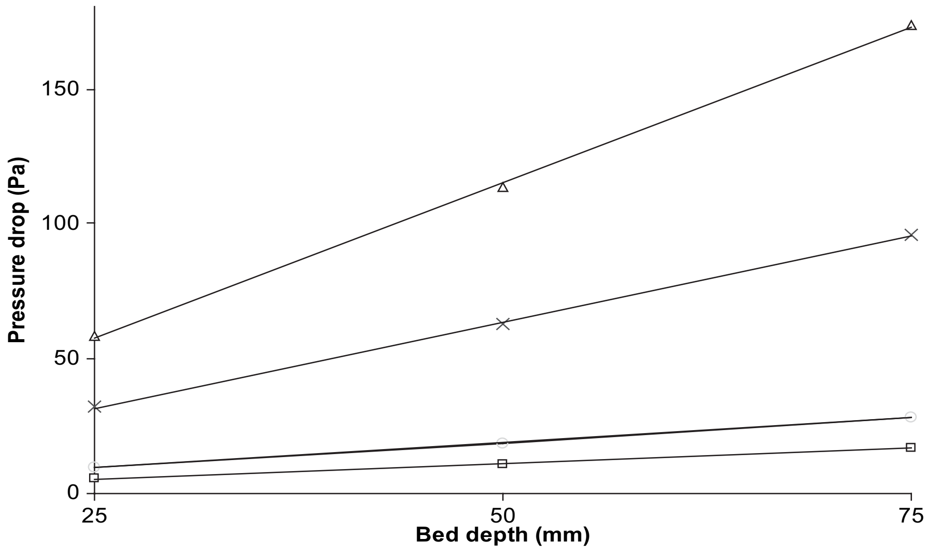

Figure 2 Effect of bed depth on airflow resistance of large kabuli chickpea at moisture content of 9.32% (wet basis), bulk density of 770 kg/m^3 and four airflow rates: (Δ) 0.3; (×) 0.2; (○) 0.1; and (□) 0.08 m^{3}s^{-1}m^{-2}.

The values of coefficient of determination were greater than 0.99 in all tests indicating good fit of the models. In order to determine how these models fit to the whole airflow rate range, percentage errors of pressure drop predictions were calculated. The relative error at each airflow rate was defined by:

$$\text{Relative error} = \frac{(\text{predicted}_i - \text{experimental}_i)}{\text{experimental}_i} \times 100. \qquad (6)$$

Figure 3 shows the typical effect of airflow rate on percentage errors of pressure drop predictions in chickpea. For large kabuli chickpea at moisture content of 9.32% and bulk density of 770 kg/m^3, the curve became almost horizontal at airflow rates greater than 0.1 m^{3}s^{-1}m^{-2}. The percentage of error approached zero at high airflow rates. Similar results were observed for other chickpea samples in the experimental trials.

The standard stepwise regression procedure of the SAS software, was used to solve for the parameters of the relationship between the airflow resistance and the experimental variables. It was observed that each of the variables significantly improved the model at the 0.01% level of significance. Equation 7 was used to describe the relationship between airflow resistance and experimental data,

$$\frac{\Delta P}{L} = aQ^2 + bMQ + c\rho_b Q. \qquad (7)$$

The coefficient of determination (R^2), regression coefficients, and standard errors of estimates are presented in Table 6. The airflow variable (Q), had the largest effect on pressure drop, followed by moisture content (M) and bulk density (ρ_b) in that order. It was

Table 3 Estimated parameters of three airflow resistance models at different combinations of moisture content and bulk density for large kabuli chickpea.

		Moisture content* (% w.b.)								
		M_1 9.32			M_2 12.72			M_3 16.10		
		Bulk density (ρ_b) (kg/m^3)								
Model	Constants	ρ_{b1} = 770	ρ_{b2} = 827.3	ρ_{b3} = 837.9	ρ_{b1} = 764.3	ρ_{b2} = 821	ρ_{b3} = 831.6	ρ_{b1} = 738.9	ρ_{b2} = 778.5	ρ_{b3} = 809.6
Shedd										
	A	1639.8	1754.2	1588.4	1287.6	13.94.3	1264.9	1063.7	1277.4	1491.4
	B	1.63	1.62	1.52	1.70	1.69	1.62	1.59	1.58	1.51
	$R^{2\dagger}$	0.9989	0.9914	0.9996	0.9992	0.9968	0.9960	0.9981	0.9991	0.9989
	MSE‡	18.98	17.19	7.40	7.30	36.47	41.85	14.70	10.07	13.25
Hukill & Ives										
	C	6928.2	7329.4	5603.2	6069.1	6231.4	5395.8	4324.7	4937.9	5049.3
	D	47.49	44.79	21.61	86.72	69.52	48.01	37.78	31.47	18.82
	R^2	0.9987	0.9990	0.9988	0.9995	0.9973	0.9953	0.9971	0.9986	09983
	MSE	21.59	19.94	24.06	4.55	30.09	48.21	22.22	16.26	19.73
Ergun										
	E	227.3	261.29	340.59	142.53	166.18	184.13	174.82	225.99	340.63
	F	1379.2	1848.3	1626.5	1348.1	1446.6	1340.5	1123.1	1333.3	1509.9
	R^2	0.9980	0.9985	09979	09997	09978	09942	09958	0.9971	09976
	MSE	23.69	29.62	41.09	2.72	24.15	59.08	32.10	25.68	27.48

*Value represents an average of three replicates of the moisture contents of samples, which were selected before and after each experiment. †Coefficient of multiple determination for relationship between predicted and measured values. ‡Mean square error (MSE) of predicted values with respect to the measured values.

Table 4 Estimated parameters of three airflow resistance models at different combinations of moisture content and bulk density for small kabuli (chico) chickpea.

		Moisture content* (% wet basis)								
		M_1 9.82			M_2 15.10			M_3 18.20		
		Bulk density (ρ_b) (kg/m^3)								
Model	Constants	ρ_{b1} = 806.8	ρ_{b2} = 841.5	ρ_{b3} = 863.4	ρ_{b1} = 785.6	ρ_{b2} = 819.5	ρ_{b3} = 840.8	ρ_{b1} = 753	ρ_{b2} = 788.4	ρ_{b3} = 815.3
Shedd										
	A	2372.5	1608.3	1779.6	1554.5	1047.3	982.4	1312.4	1411.6	1951.6
	B	1.68	1.43	1.44	1.63	1.40	1.38	1.58	1.43	1.56
	$R^{2\dagger}$	0.9989	0.9986	0.9998	0.9989	0.9979	0.9951	0.9983	0.9944	0.9942
	MSE‡	34.82	32.63	6.58	17.72	21.90	47.65	20.01	101.52	163.05
Hukill & Ives										
	C	10528.9	4676.9	5306.9	6491.2	2868.6	2572.5	5197.2	4200.5	7266.1
	D	64.71	11.28	12.34	46.45	9.45	8.35	33.80	11.94	26.19
	R^2	0.9994	0.9971	0.9993	0.9990	09959	0.9920	09973	09919	09928
	MSE	20.88	67.57	19.07	14.96	42.93	75.98	31.96	145.73	202.07
Ergun										
	E	294.00	484.00	504.08	224.77	346.53	348.97	227.33	418.15	384.12
	F	2476.8	1533.4	1726.0	1628.7	967.9	879.6	1379.2	1350.3	2023.7
	R^2	0.9996	0.9960	0.9988	0.9989	0.9948	0.9906	0.9961	0.9903	0.9913
	MSE	11.40	90.10	33.08	16.45	53.54	88.29	46.72	172.00	242.64

*Value represents an average of three replicates of the moisture contents of samples, which were selected before and after each experiment. †Coefficient of multiple determination for relationship between predicted and measured values. ‡Mean square error (MSE) of predicted values with respect to the measured values.

Table 5 Estimated parameters of three airflow resistance models at different combinations of moisture content and bulk density for desi chickpea.

		Moisture content* (% wet basis)								
		MC_1 9.56			MC_2 13.83			MC_3 17.15		
		Bulk density (ρ_b) (kg/m^3)								
Model	Constants	ρ_{b1} = 754.4	ρ_{b2} = 792.6	ρ_{b3} = 809.6	ρ_{b1} = 720.5	ρ_{b2} = 756.6	ρ_{b3} = 772.9	ρ_{b1} = 693.6	ρ_{b2} = 741.7	ρ_{b3} = 760.8
Shedd										
	A	1921.5	1589.0	2256.2	1392.6	1165.3	1984.4	1689.4	1746.8	1879.0
	B	1.52	1.46	1.54	1.62	1.55	1.78	1.73	1.52	1.45
	$R^{2\dagger}$	0.9962	0.9990	0.990	09971	0.9876	0.9886	0.9979	0.9985	0.9973
	MSE‡	108.98	21.72	38.52	36.43	124.97	218.88	32.03	36.02	84.43
Hukill & Ives										
	C	6830.3	4841.2	7899.2	5693.6	3841.9	9943.2	8443.9	6027.4	5785.7
	D	21.95	13.34	21.89	42.34	19.52	152.4	120.83	20.26	13.41
	R^2	0.9948	0.9991	0.9990	0.9973	0.9899	0.9889	0.9982	0.9979	0.9957
	MSE	147.66	20.42	36.52	33.40	99.91	202.37	26.72	48.73	133.51
Ergun										
	E	412.88	428.52	470.01	209.64	241.68	177.50	165.54	383.56	518.71
	F	1968.8	1557.9	2304.1	1455.7	1171.4	1974.0	1760.3	1777.0	1833.0
	R^2	0.9934	0.9988	0.9987	0.9972	0.9914	0.9911	0.9987	0.9972	0.9944
	MSE	186.05	26.28	48.7	34.34	84.76	166.42	20.36	66.07	168.74

*Value represents an average of three replicates of the moisture contents of samples, which were selected before and after each experiment. †Coefficient for multiple determination for relationship between predicted and measured values. ‡Mean square error (MSE) of predicted values with respect to the measured values.

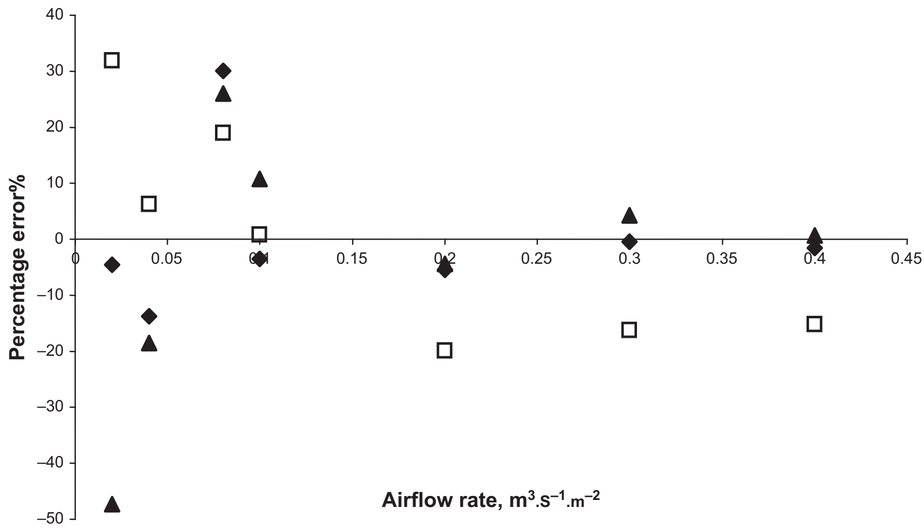

Figure 3 Percentage error in the prediction of pressure drop as a function of airflow rate of large kabuli at moisture content of 9.32% wet basis, bulk density of 770 kg/m^3. (Δ) Shedd model, (♦) Hukill and Ives model, and (□) Ergun model.

Table 6 Estimated model coefficients and standard error obtained by stepwise regression procedure.

Model coefficient	Large kabuli	Small kabuli (chico)	Desi
a	1656.75	1654.75	1672.72
b	−22.81	−23.24	−16.08
c	0.62	0.87	0.82
R^2	0.97	0.96	0.95
MSE	839.37	1386.54	2302.10

observed that pressure drop of various chickpea samples increased with increasing airflow rate and bulk density, and decreasing moisture content. Similar result was reported by Dairo and Ajibola[8] for sesame seed.

CONCLUSION

The pressure drop across the column of various chickpea samples increased linearly with the depth of seed column. The Shedd, Hukill and Ives, and Ergun models fit very well to the experimental data especially at high airflow range (0.1 – 0.4 $m^3s^{-1}m^{-2}$). The airflow resistance of various chickpea samples ($\Delta P/L$) increased with increasing airflow rate (Q) and bulk density (ρ_b), and decreasing moisture content (M).

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