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Airflow Resistance in Walnuts

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ABSTRACT

The harvested walnut has a relatively high moisture content of 30% compared with the safe storage moisture content of 8%. One of the common means of reducing the moisture content is by drying. For design of drying and other aeration systems for agricultural products including walnuts, the relationship between the drop in pressure and airflow velocity must be known. An airflow resistance apparatus was designed and manufatured to measure the airflow resistance of walnuts. This apparatus consisted of an air compressor, a rotameter, a cylindrical bin and an inclined U-tube manometer. The pressure, drops at airflow velocities of 0.085 to 0.55 (m^3/s)/m^2, were measured at a constant depth of the nuts. Airflow resistance equations were fitted to the measured data. The results showed that, by increasing airflow rates, an increased drop in pressure was achieved through out walnut column. To study the effect of walnut moisture content on airflow resistance, the drop in pressure was measured at different moisture contents levels of 8.6%, 15.5%, 21.3% and 27%. Results indicated that the drop in pressure decreased with increasing moisture content, especially for high airflow rates.

Keywords: Airflow, Moisture, Pressure drop, Resistance, Walnut.

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INTRODUCTION

The relationship between a drop in pressure and the rate of airflow through an agricultural product is important in the design of drying or cooling systems (ASAE Standard, 1995). Resistance to airflow is a function of both product and air properties (Jayas *et al.*, 1987). The study of airflow resistance through agricultural products was started by Stremen in 1931 and continued by others (Tabil and Marshall, 1999). Shedd (1953) studied airflow resistance for cereals and presented equations and curves for a number of grains. Bakker-Arkema *et al.* (1969) studied the airflow resistance for cherry core and the effect of moisture on this resistance. Parsons obtained the curves for the relationship between a drop in pressure and air velocity through the nuts in 1971. A study of airflow resistance for potatoes was undertaken by Abram and Fish (1982), and root products were studied by Neale and Messer (1976). For all the products tested, the relationship between an air pressure drop per unit depth ($\Delta P/L$) and velocity (V) was presented as below:

$$\Delta P/L = A\,(V)^B \quad (1)$$

Where V is the airflow rate per unit area, (m^3/s)/m^2, ΔP is the air pressure drop (Pa) and L is the depth of product (m).

A and B are experimental constants depending on type of product and test conditions.

For all products, the constant B is very close to 1.8 (Tabil and Marshall, 1999). Sokhansanj *et al.* (1990) studied the effect of moisture on airflow resistance through lentil seeds. They found that, with the lentil moisture content changing from 10.4 to 19.9%, the airflow resistance reduced by 22.5%. Tabil and Marshall (1999) studied airflow resistance in sugar beet and the effect of beet size, airflow direction and the amount of external material on the resistance. It was found the small beets had 1.9 times more

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airflow resistance than the large ones. The external material also increased the airflow resistance and the horizontal airflow showed more resistance than the vertical airflow through the beets.

The objective of this study was to determine:
(i) the effect of air velocity variation on walnut airflow resistance, and
(ii) the effect of walnut moisture on airflow resistance.

MATERIALS AND METHODS

Nut Physical Properties

Walnuts for use in experiments for this study were picked randomly from gardens in Toosirkan, Hamedan, Iran. For measuring the moisture content, samples were dried in an oven at 43°C for 72 hours (Rumsey, 1984). Measurements were taken for the average length and diameter of 30 nuts from the sample, the surface area was calculated using the following equation presented by Rumsey, (1981):

$$S_w = 0.5\pi W^2\left(1+\frac{L^2}{W\sqrt{L^2-W^2}}\sin^{-1}\frac{\sqrt{L^2-W^2}}{L}\right) \quad (2)$$

In this equation; L: is the average nut length (mm), W: is the average nut diameter (mm), S_w: is the nut surface area (mm).

For measuring the average volume of nuts (V_w), a sample of 30 nuts was taken randomly. The nuts were put inside a scaled tube and the tube was filled up with water to cover the nuts. The volume of the nuts was calculated from difference between the total volume and water volume. The average volume of the nuts (V_w) was obtained by dividing the volume of nuts by the number of nuts. The equivalent diameter (D_w) of the nuts was calculated from equation 3, assuming the nuts are nearly spherical:

$$D_w = \left(\frac{6V_w}{p}\right)^{1/3} \quad (3)$$

The sphericity of the nuts (θ_w) was obtained using following equation (Rumsey, 1981):

$$\theta_w = \frac{6V_w}{D_w S_w} \quad (4)$$

The average mass of the nuts was calculated by dividing the total mass of the 30 nuts by the number of nuts. The bulk density (ρ_b) of the nuts was obtained from the mass of the nuts that filled the bin, divided by the volume of the bin. Particle density (ρ_p) was calculated from a ratio of the average mass to the average volume and, finally, the porosity was calculated from following equation (Neale and Messer, 1976):

$$Porosity = \frac{\rho_p - \rho_b}{\rho_p} \quad (5)$$

Airflow Resistance Measurement

The equipment used comprised an air compressor, a rotameter, a plenum, a screen plate, a walnut bin and an inclined U–tube manometer for measuring pressure (Figure 1). The nut bin is a cylinder with a 23 cm diameter and a 120 cm height made from 2 mm steel sheet. The volume of the bin is 0.049 m^3. Four air tabs were installed on the cylinder wall to measure pressure difference at different depths of relative base pressure. A perforated plate was placed under the nut bin, containing round holes of 4mm diameter and 40% opening to the floor. An air rotameter was used for measuring airflow velocity manufactured by Azmoon Motammam company in Tehran, Iran. The device is capable of measuring airflows of 200-1300 l/min. A control was valve installed between the rotameter and the compressor.

To measure the effect of velocity on airflow resistance through the nuts, the bin was filled with the nuts up to 100 cm depth. Measurements of pressure drops were taken at 12 air velocities from 0.085 to 0.55 $(m^3/s)/m^2$. Each test repeated was four times and the bin was filled for each repetition.

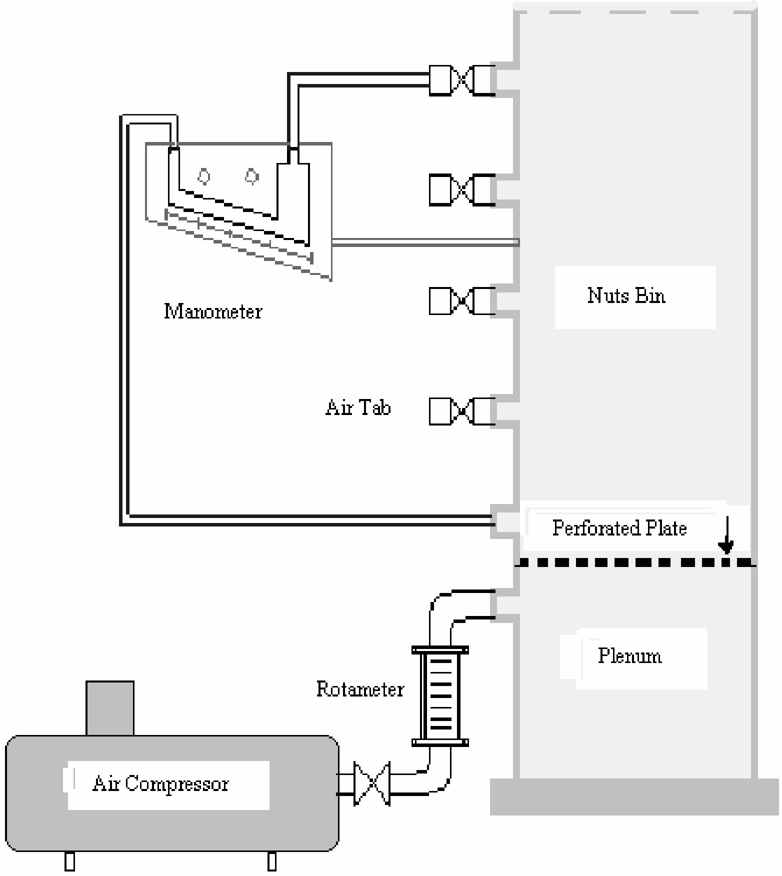

Figure 1: Airflow resistance measurement equipment.

To measure the effect of moisture on airflow resistance through the nuts, four different moisture levels (8.6, 15.5, 21.3 and 27%) and four airflow rates of 300, 600, 900 and 1200 L/min (expressed air velocities the metric system as 0.12, 0.25, 0.37 and 0.51 m/s) were applied. The experiment was performed using complete randomized design with two factors comprising nut moisture and air velocity, each repeated four times. All tests were conducted at a 100 cm depth of nuts in the bin.

Airflow Resistance Data Analysis

Two models were used to explain the data. The first model was that presented by Shedd (1953):

$$\Delta P/L = A\,(V)^B \quad (6)$$

where V is the airflow rate per unit area ($(m^3/s)/m^2$), ΔP is the pressure drop (Pa) and L is the depth (m).
A and B are the experimental constants for each test condition.

The second model was that of Bakker-Arkema *et al.*, (1969):

$$\Delta P/L = MV + NV^2 \quad (7)$$

where M and N are constants related to the test condition and type of product and could be obtained from regression analysis.

To analyze the relationship between air pressure drop and velocity, data was processed using the Excel computer program for regression.

RESULTS AND DISCUSSIONS

The physical properties of the nuts are given in Table 1. Resistance to airflow through the tested nuts which is described as a relationship between air velocity and pressure drop per unit depth, is shown in Table 2. Two mathematical models (equations 6 and 7) were applied to describe this. The constants A and B for the first model and M and N for the second model were obtained at a constant moisture content of 8.6%, (Table 2). In this table, air pressure drop per unit depth for a velocity of 0.5 $(m^3/s)/m^2$ which is, in practice, used for the nut drier was also calculated. The value for B in the first model is the same as the amount for products of an equivalent shape, such as potatoes (Irvine *et al*., 1993) and sugar beet (Tabil, 1999). For all these products, the constant B = 1.8 is obtained. The value obtained for M and N in the second model are nearly the same as the values reported by Rumsey (1981). He obtained N=427 and M= 27.8 for a fixed bed walnut dryer that are very close to our values of N = 413 and M= 38.3 (Table 2). Rumsey also found the pressure loss to be equal to 120.3 Pa/m, where as in this study it was found to be 122.54 Pa/m. This difference could be due to difference in size of the nuts samples. Figure 2 shows the curve of relationship between air pressure loss and velocity.

To study the effect of moisture content on resistance to airflow, four levels of nut moisture content (8.6, 15.5, 21.3 and 27%) were used. The air flow rates were 300, 600, 900 and 1200 L/min. Measurements of an air pressure drop with four replications were carried out for each level of moisture and flow rate. Figure 3 shows the curves for pressure drop ($\Delta P/L$) vs. the moisture content (m). The following polynomial equation was fitted to the data:

$$\Delta P/L = A(m)^3 + B(m)^2 + C(m) + D \qquad 8)$$

The constants A, B, C and D are given in Table 3, where pressure drops per unit depth at two levels of moisture content, 8.6% and 27%, were calculated. At these two moisture levels, there is no significant difference in pressure loss at low flow rates (300 and 600 L/min) but, for a high flow rate (1200 L/min), pressure loss for the two levels of moisture had significant difference and, with an increase in moisture, the pressure loss decreases. Table 4 shows the results of the analysis of variance for different levels of moisture, velocity and their interaction on

Table 1. Physical properties of a nut sample used for the experiment.

Moisture Content (%)	8.6	Sphericity of Nuts (decimal)	0.932
Average Diameter Dw (m)	0.0307	Mass of Nut Sample (kg)	15
Average Length L (m)	0.034	Average Mass of a Nut (kg)	0.0123
Average Surface S_w (m^2)	3.3×10^{-3}	Bulk Density (kg/ m^3)	333.33
Average Volume V_w (m^3)	1.6×10^{-5}	Particle Density (kg/ m^3)	637.61
Equivalent Diameter D_r (m)	0.0312	Porosity (%)	47

Table 2. Pressure drop ($\Delta P/L$) for two models (equations 6 and 7) at V=0.5 $(m^3/s)/m^2$.

Model 1				Model 2			
$\Delta P/L = AV^B$				$\Delta P/L = MV + NV^2$			
A	B	R^2	$\Delta P/L$	M	N	R^2	$\Delta P/L$
429.7	1.8045	0.999	123.38	38.269	413.63	0.988	122.54

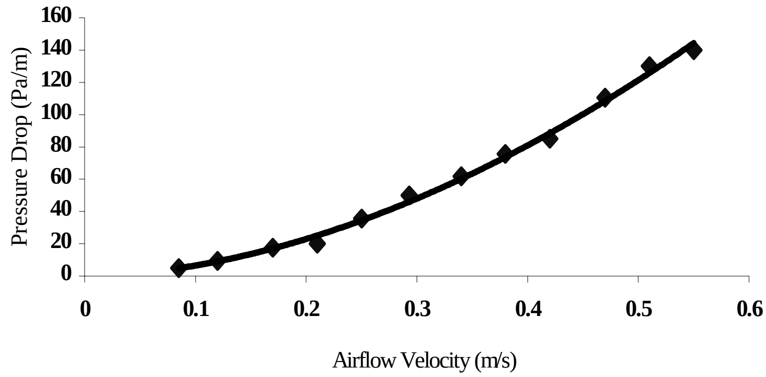

Figure 2. Airflow resistance through the nuts

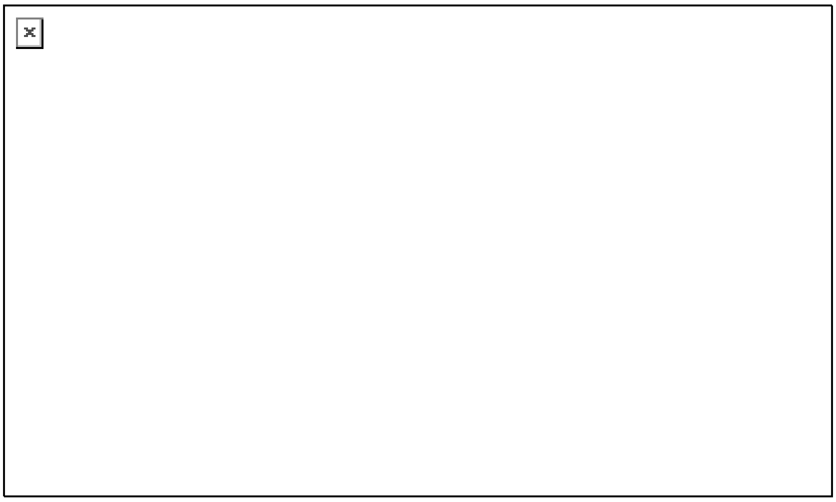

Figure 3. Pressure drop vs. moisture content for different airflow.

pressure loss. The effect of moisture, velocity and interaction of both factors are significant at α=1% level.

Comparison of means were performed on the basis of Dunkun's test. Table 5 and Table 6 show the results of a means comparison test. Table 5 shows that, with an increase in the nuts, moisture, no significant difference between pressure loss at moisture levels of 8.6% and 15.5%. But there is a significant difference in the pressure loss when comparing moisture levels of 21.3% and 27% with other moisture levels. The mean of pressure loss with an increase in moisture from 8.6% to 15.3% decreases by 11.9%, with increase in moisture to 21.3%, it decreases by 29.06% and with an increase to 27% it decreases by 38.58%. This could be explained, on the assumption that having higher moisture content causes tiny pores on the external surface of the nuts to be filled with moisture. Thus the surfaces are softer and show less resistance against airflow through the nuts. The results obtained here are nearly the same as for products such as lentils (Sokhansanj *et al.*, 1990) and rice (Siebenmorgen, 1987). Table 6 shows that there is a significant difference between pressure losses at different air velocities. With an increase in velocity, the mean of pressure loss also increases. With an increase in velocity from 0.12 to 0.25 m/s, the

Table 3. Effect of nut moisture (m) on the pressure drop per unit depth (ΔP/L) for different flow rates (L=100 cm, porosity =.47).

Flow Rates L/min	$\Delta P/L = A(m)^3 + B(m)^2 + C(m) + D$					Mean of pressure drop ΔP/L (Pa/m)	
	A	B	C	D	R^2	Moisture	
						8.6%	27%
300	-0.0007	0.039	-0.84	14.37	0.9845	9.25	7.3
600	-0.0001	0.0195	-1.364	45.48	0.9976	35.62	21.89
900	-0.0012	0.0975	-3.904	101.46	0.9980	75.62	40.75
1200	0.0048	-0.02386	1.2132	127.88	0.9976	127.25	82.31

Table 4. Analysis of variance of air pressure drop.

Variation source	df	Total Sq.	Mean Sq.	F
Moisture	3	5477.051	1825.684	714.027[a]
Velocity	3	84144.491	28048.164	10969.679[a]
Moisture×Velocity	9	2940.678	326.743	127.789[a]
Errors	48	122.730	2.557	
Total	63	92684.959		

[a] significant at 1% level.

mean of pressure loss increases 3.35 times and, with an increase to 0.51 m/s, it increases 12 times. As the results indicate, the drop in pressure is lower for low airflow velocities than for high velocities. This is because, when there is low airflow velocity, the air passes through the pores between the nuts easily and loses less energy. But, when the velocity is high, there are more hits between air particles and the nuts and so the air loses more energy than before.

CONCLUSIONS

Results from this study indicate that increasing air flow rates decreases the drop in pressure through the walnut column. Another conclusion from this study is that airflow pressure drops decrease with an increas in moisture content, especially for high airflow rates. The results also indicate that the effect of airflow velocity is much higher than the effect of the nut moisture content on pressure loss.

ACKNOWLEDGEMENT

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Table 5. Test of means[a] comparison for the moisture content of the nuts based on Dunkun's test.

Moisture (%)	Pressure drop means ΔP/L	Group
8.6	61.97	A
15.5	54.54	AB
21.3	43.96	C
27.0	38.06	D

[a]Means are compared at 5%

Table 6. Test of means[a] comparison for the air velocity based on Dunkun's test.

Velocity, m/s (airflow, L/min)	Pressure drop means ΔP/L	Group
8.6	8.23	A
15.5	27.63	B
21.3	58.41	C
27.0	104.25	D

[a]Means are compared at 5%.

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مقاومت به عبور جریان هوا از میان توده گردو درمخزن

ع. رجبی‌پور، ف. شهبازی، س. محتسبی، ا. طباطبایی‌فر

چکیده

رطوبت گردو هنگام برداشت (حدود ۳۰٪)، خیلی بیشتر از میزانی است که برای نگهداری آن مناسب است (۸٪). یکی از روشهای مرسوم برای نگهداری گردو، کاهش رطوبت اضافی یا خشک کردن آن است. یکی از پارامترهای مهم در طراحی خشک‌کن‌ها و دیگر سیستمهای هوادهی برای محصولات کشاورزی از جمله گردو و انتخاب دمنده برای آنها، رابطه بین افت فشار در واحد عمق و سرعت جریان هوا از میان توده یا مقاومت به عبور جریان هوای این محصول است. برای اندازه‌گیری مقاومت به عبور جریان هوا ازمیان توده گردو دستگاهی طراحی و ساخته شده که شامل یک کمپروسور هوا، یک بده‌سنج جریان هوا (رتامتر)، یک مخزن استوانه شکل و یک فشارسنج U شکل است. مقاومت به عبور جریان هوا از میان توده گردو در دامنه سرعت هوا از ۰/۰۸۵ تا ۰/۵۵ متر بر ثانیه به صورت رابط بین افت فشار در

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واحد عمق و سرعت جریان هوا از میان توده بدست آمد. همچنین اثر درصد رطوبت گردو بر مقاومت به عبور جریان هوا در ٤ سطح ٨/٦، ١٥/٥ ، ٢١/٣ و ٢٧ درصد مورد آزمایش قرار گرفت. نتایج نشان می‌دهد که مقاومت به عبور جریان هوا در سرعت‌های بالای جریان هوا (٠/٥٥ متربرثانیه) با افزایش رطوبت کاهش می‌یابد.