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Aerodynamic properties of *Turgenia latifolia* seeds and wheat kernels

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A b s t r a c t. Aerodynamic properties of solid materials have long been used to convey and separate seeds and grains during post harvest operations. *Turgenia latifolia* (broadleaf false carrot) seeds that interfere with milling of wheat can be separated by some type of pneumatic means if aerodynamic properties of these two materials are well known. The objective of this study was evaluation of the aerodynamic properties of *Turgenia latifolia* seeds and wheat kernels as a function of moisture content, 7 to 20.8% w.b. The results showed that the terminal velocity of wheat kernels increased nonlinearly from 9.587 to 9.25 m s^{-1} for an increase in moisture content. Over this same moisture content the terminal velocity of *Turgenia latifolia* seeds varied from 6.775 to 6.877 m s^{-1}. The drag coefficient of wheat kernels and *Turgenia latifolia* seeds decreased nonlinearly from 0.0543 to 0.0528 and 0.0512 to 0.0458, respectively, as moisture content increased from 7 to 20.8% w.b. The analysis of variance showed that there was a significant difference between the terminal velocity and the drag coefficient of wheat and *Turgenia latifolia* seeds at the 1% probability level. The moisture content had a significant effect on the terminal velocity of wheat kernels.

K e y w o r d s: aerodynamic properties, separation, *Turgenia latifolia*, wheat

INTRODUCTION

In handling and processing of agricultural products air or water are often used as a carrier transport for the separation of the desirable product from that of unwanted materials (Mohsenin, 1978). Seed separation can be accomplished by using pneumatic separators, screen cleaners, or gravity tables. Many commercial cleaners incorporate more than one of these cleaning methods (Hauhouot *et al*., 2000). The pneumatic separation and conveying systems have been used in agricultural machinery and food processing equipment for many years. When an air stream is used for separating a product such as wheat from its associated foreign materials, such as straw and chaff, knowledge of aerodynamic characteristics of all the particles involved is necessary. This helps to define the range of air velocities for effective separation of the grain from foreign materials. For this reason, the terminal velocity (V_t) has been used as an important aerodynamic characteristic of materials in such applications as pneumatic conveying and their separation from foreign materials (Mohsenin, 1978).

Turgenia latifolia from the *Apeaceae* family is a summer annual weed. This weed is common in wheat fields of Iran and the Middle East region. Its seeds have an adverse effect on the quality of the flour if they is not separated before or during the milling process. Separation of *Turgenia latifolia* seeds from wheat kernels in the milling process is very difficult due to their morphological feathers. To overcome this problem, some type of equipment is needed to be designed which performs this separation. However, in order to do this, thorough knowledge on the aerodynamic properties of wheat as well as *Turgenia latifolia* seeds may lead to a point that some type of pneumatic device can be envisaged.

Several investigators determined the V_t of various seeds such as African breadfruit seeds by Omobuwajo *et al*. (1999), amaranth seeds by Kram and Szot (1999), cheat seed by Hauhouot *et al*. (2000), millet grain by Baryeh (2002), pine nuts by Ozguven and Vursavus (2005, wheat kernel by Khoshtaghaza and Mehdizadeh (2006), makhana by Jha and Kachru (2007) and pistachio nut by Razavi *et al.* (2007). But there is no information about the aerodynamic properties of *Turgenia latifolia* seed.

The objective of this study was to investigate the aerodynamic properties of *Turgenia latifolia* seeds and wheat (cv. Sardary) kernels as a function of moisture content. Tests were conducted over a range of moisture contents from 7 to 20.8% w.b., which spans the moisture range of harvest to the milling operation.

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MATERIALS AND METHODS

Wheat and *Turgenia latifolia* seeds were cleaned manually to remove foreign materials such as dust, dirt, stones, chaff and broken kernels. The seeds were then classified into two grades based on their length, cut points being 6.92 and 7.54 mm for wheat and *Turgenia latifolia* seeds, respectively. Grade A and B referred to above and below the cut points, respectively.

The initial moisture content of both types of seeds was determined using oven tests at 103±1ºC for 19 h (ASAE, 1998). The initial moisture content of wheat and *Turgenia latifolia* seeds was 10 and 7% w.b., respectively. The seeds were conditioned to higher moisture content by adding pre-defined amounts of distilled water. The samples were then stored at 5ºC for a week to enable the moisture to distribute uniformly throughout the seeds (Al-Mahasneh and Rababa, 2007).

Wheat and *Turgenia latifolia* seeds were left to dry in the oven at 70 and 30ºC, respectively, for different periods of times, to obtain five levels of moisture content, namely, 20.8, 17, 14, 10 and 7% w.b.

EXPERIMENTAL APPARATUS

To determine the V_t value of wheat and *Turgenia latifolia* seeds, a vertical wind tunnel was designed based on recommendations by Tabak and Wolf (1998) and Afonso *et al*. (2007). A centrifugal fan powered by one HP motor was used in the inlet of the wind tunnel to supply air flow. The air flow rate of the fan was controlled at inlet by a diaphragm. To measure the V_t of the seeds, a uniform velocity field was required in the cross section of the tunnel, where seeds were suspended. For this purpose, two straightener sections were set up which consisted of one layer of fine wire mesh screen located above the honeycomb. The final section of the wind tunnel consisted of a plexiglass region where the V_t of grain was measured.

To determine the terminal velocity, each seed was placed in the centre of the cross section of the wind tunnel on the screen. The air flow was then increased until the seed flotation point. At this moment, when the rotational movement of the seed was lowest, the air velocity was measured using a hot-wire anemometer with an accuracy of 0.1 m s^{-1}. The V_t of each seed was measured two times. For each condition the V_t was calculated as the average of the velocity values obtained at the centre of the test section and at the four equidistantly distributed points on two orthogonal axes located at the test section. To determine the V_t at each moisture content level, five seeds were selected and used as five replications in the statistical analysis.

In free fall, the object will attain a constant velocity, V, at which the gravitational force, F_g, equals the resisting upward drag force, F_r (Mohsenin, 1978). This constant velocity is called V_t :

$$\text{If } F_g = F_r \Rightarrow V = V_t .$$

By substituting the expressions of F_g and F_r, in the above equation, the expression for the V_t will be:

$$w\left[\frac{(\rho_t - \rho_f)}{\rho_t}\right] = \frac{1}{2} C A_p \rho_f V_t^2 ,$$

$$V_t = \left[\frac{2w(\rho_t - \rho_f)}{C\, A_p\, \rho_t \rho_f}\right]^{1/2} , \qquad (1)$$

$$C_d = \frac{2w(\rho_t - \rho_f)}{V_t^2\, A_p\, \rho_t \rho_f} ,$$

$$A_p = \frac{\pi}{4} L W , \qquad (2)$$

where: A_p is projected area (m^2), C_d is drag coefficient (dimensionless), L is length of kernel (mm), V_t is terminal velocity (m s^{-1}), w is weight of kernel (kg m s^{-2}), W is width of kernel (mm), ρ_t, ρ_f are seed and air densities (kg m^{-3}).

The drag coefficient was calculated using Eq. (1). To calculate the drag coefficients of two products (at both grades), the V_t values were measured using the procedure described in the previous section. The true density of the seeds was measured using toluene displacement method (Chakraverty and Poul, 2001; Mohsenin, 1978). The projected area of the seeds was estimated using Eq. (2). The major dimensions of the seeds (L and W) were also measured using a digital vernier caliper with an accuracy of ± 0.01 mm (Gupta *et al*., 2007). The value of air density was taken as 1.1774 kg m^{-3} at temperature of 27ºC (Irtwange and Ugbeka, 2003). Each experiment was conducted at all moisture content levels.

Data analysis of the V_t and the drag coefficient of wheat and *Turgenia latifolia* seeds were carried out using a nested split plot form arranged in Complete Randomised Design (CRD) with five replications. Wheat and *Turgenia latifolia* seeds at two size classifications (A and B) were used as a main plot and five moisture content levels (7, 10, 14, 17 and 20.8% w.b.) were used as a sub plot. Mean comparison of factors was carried out at 5% probability level. The V_t and the moisture content data of different seeds were fitted to linear, power, exponential and polynomial models. The models were evaluated according to the statistical criterion R^2 for verifying the adequacy of fit. The best model with the highest R^2 was selected to predict the V_t of seeds as a function of the moisture content. Data were analysed by MSTATC, SPSS and MATLAB software.

RESULTS AND DISCUSSION

The results determined that there was a significant difference between the V_t of wheat and *Turgenia latifolia* seeds (at both grades A and B). Also the effect of seed moisture content on this property was significant (Table 1). The V_t of wheat kernels at both grades A and B increased from 9.25 to 9.587 m s^{-1} and from 8.353 to 8.757 m s^{-1}, respectively, as the moisture content increased from 7 to 20.8% w.b. (Fig. 1). The maximum V_t value of wheat kernels was obtained in grade A (9.58 m s^{-1}), at a moisture content of 20.8% w.b., and the minimum amount was obtained in grade B (8.35 m s^{-1}), at a moisture content of 7% w.b. However, in a comparison of the means, the moisture content did not significantly affect the V_t of *Turgenia latifolia* seeds at both grades; although as moisture content increased from 7 to 20.8% w.b., the V_t of *Turgenia latifolia* seeds varied from 6.775 to 6.877 m s^{-1} and from 5.853 to 5.983 m s^{-1} at both grades A and B, respectively. *Turgenia latifolia* seeds had the maximum value of V_t in grade A (6.88 ms^{-1}), at the moisture content of 20.8% w.b., and minimum value of V_t of *Turgenia latifolia* seeds was related to grade B (5.85 m s^{-1}), at the moisture content of 7% w.b. These results are in agreement with published literature for some seeds. Gupta *et al*. (2007) showed that in the moisture range of 6 to 14% d.b., the V_t of NSFH-36, PSF-118 and Hybrid SH-3322 variety of sunflower seed increased from 2.93 to 3.28, 2.54 to 3.04, and 2.98 to 3.53 m s^{-1}, respectively. Zewdu (2007) measured the V_t of Tef grains. He reported that it increased linearly from 3.08 to 3.96 m s^{-1} with increasing moisture content from 6.5 to 30.1% w.b. Hauhouot *et al*. (2000) showed that the V_t of wheat is 7.84 m s^{-1}. The V_t of millet grain varied from 2.75 to 4.63 m s^{-1} for an increase in moisture content from 5 to 22.5% d.b. (Baryeh, 2002). Similar results were reported for cotton seeds (Tabak and Wolf, 1998), coffee cherries and beans (Afonso *et al*., 2007), African yam bean (Irtwange and Ugbeka, 2003).

The V_t data for wheat kernals were fitted as a function of moisture content to four mathematical models. These models were evaluated for verifying the adequacy of fit using the R^2 value. By comparing the average values of R^2, it was obvious that the polynomial model had the highest R^2 value (Table 2). Accordingly, the polynomial model was selected as a suitable model to predict the V_t of wheat kernels as a function of moisture content. Razavi *et al*. (2007) developed a linear equation between the V_t of pistachio nut and kernel as a function of moisture content. Zewda (2007) reported that the V_t of Tef grain was linearly related to moisture content. However, Afonso *et al*. (2007) reported a nonlinear equation for the V_t of coffee cherry and bean as a function of combination of moisture content and true density.

As shown in Fig. 1, the V_t values of wheat kernels for both grades A and B were higher than those of *Turgenia latifolia* seeds at both grades and at all moisture content levels. The V_t values of wheat and *Turgenia latifolia* seeds could be arranged in decay order from maximum to minimum as: wheat grade A, and B, *Turgenia latifolia* grade A and B. At least, there was 1.5 m s^{-1} difference between the V_t of wheat grade B and Turgenia latifolia grade A seeds.

In the milling process the operation of secondary separation of foreign materials from wheat kernels was conducted at a moisture content of 13-14% w.b. At these moisture content levels, the difference between the V_t of wheat and *Turgenia latifolia* seeds was about 2 m s^{-1}. Therefore, this difference was large enough to successfully separate *Turgenia latifolia* seeds from wheat kernels using equipment which operates on the basis of the aerodynamic properties such as the V_t.

T a b l e 1. Summary of ANOVA for the V_t and the drag coefficient

Source of variation	Degree of freedom	Mean squares	
		V_t	Drag coefficient (x10^{-6})
Seed	3	62.294*	3 186.840*
Error	16	0.259	86.797
Moisture content (seed)	16	0.063*	10.853 n.s.
Error	64	0.021	14.535

*Significant difference at 1% probability level, n.s. – no significant.

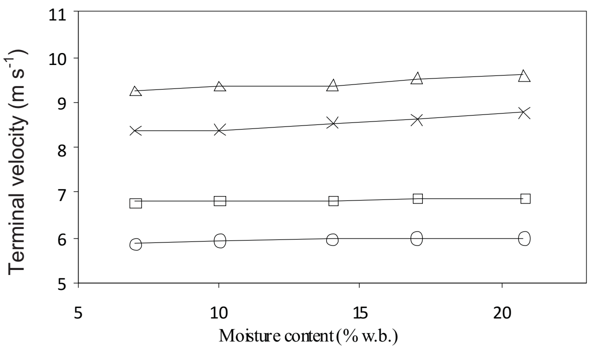

Fig. 1. Terminal velocity variation versus seed moisture content; ○ – wheat A, □ – wheat B, △ – *Turgenia latifolia* A, ✱ – *Turgenia latifolia* B.

T a b l e 2. Polynomial equations for predicting V_t of wheat kernels as a function of the moisture content

Grade	Regression equation	R^2
A	$V_t = 0.0003\, Mc^2 + 0.017\, Mc + 9.130$	0.957
B	$V_t = 0.0010\, Mc^2 + 0.007\, Mc + 8.255$	0.994

The values of the drag coefficient and the projected area of wheat and *Turgenia latifolia* seeds were calculated using Eqs (1) and (2) by measuring the V_t, true density and the two principal dimensions (length and width) of seeds (Table 3). The analysis of variance showed that there was a significant difference between the drag coefficients of wheat and *Turgenia latifolia* seeds (at both grades). The drag coefficients values of wheat kernels in grade A and B decreased from 0.0543 to 0.0528 and from 0.0570 to 0.0560 as moisture content increased from 7 to 20.08% w.b. In grade A and B, the drag coefficients of *Turgenia latifolia* seeds decreased from 0.0512 to 0.0458 and 0.0338 to 0.0295, respectively, over this same moisture content (Fig. 2). The drag coefficients of wheat kernels were higher than those of *Turgenia latifolia* seeds at both grades. This may be due to the differences in surface properties, true densities, shapes and sizes

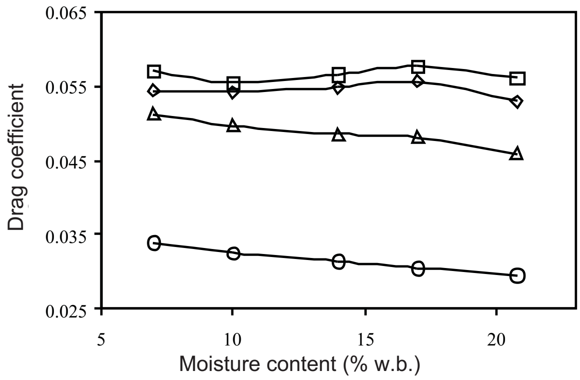

Fig. 2. Drag coefficient variation versus seed moisture content. Explanations as in Fig. 1

Table 3. Average values of V_t, true density, dimensions, projected area and drag coefficient of seeds at different moisture contents

Moisture content (% w.b.)	Terminal velocity (m s^{-1})		True density (kg m^{-3})		Length (mm)		Width (mm)		Projected area (mm^2)	
	Mean	SD*	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Wheat A										
20.8	9.58	0.32	1309.363	1.00	8.144	0.37	3.600	0.27	23.021	2.02
17	9.51	0.24	1275.900	8.33	8.006	0.36	3.530	0.25	22.221	2.08
14	9.37	0.32	1271.993	11.56	7.916	0.37	3.510	0.29	21.839	2.02
10	9.35	0.31	1279.086	3.55	7.865	0.35	3.480	0.28	21.494	1.97
7	9.25	0.26	1274.550	13.50	7.814	0.33	3.440	0.26	21.151	1.92
Wheat B										
20.8	8.75	0.20	1303.023	19.51	6.558	0.67	2.882	0.33	14.831	3.72
17	8.61	0.19	1315.778	11.12	6.482	0.69	2.792	0.22	14.218	2.38
14	8.52	0.21	1314.100	15.39	6.444	0.71	2.782	0.20	14.072	2.38
10	8.38	0.16	1284.728	4.69	6.434	0.70	2.766	0.19	13.978	2.64
7	8.35	0.11	1283.515	12.19	6.398	0.68	2.730	0.19	13.718	2.78
Turgenia latifolia A										
20.8	6.88	0.20	996.023	18.02	10.334	0.67	3.832	0.33	31.140	3.72
17	6.85	0.19	993.441	2.34	10.313	0.69	3.773	0.22	30.008	2.38
14	6.82	0.21	994.810	10.41	10.292	0.71	3.714	0.20	30.008	2.38
10	6.8	0.16	976.455	12.49	10.265	0.70	3.660	0.19	29.520	2.64
7	6.77	0.11	958.026	3.08	10.238	0.68	3.560	0.19	28.654	2.78
Turgenia latifolia B										
20.8	5.98	0.13	1057.642	22.68	7.374	0.86	2.826	0.20	16.365	2.30
17	5.98	0.19	1046.453	35.25	7.310	0.88	2.753	0.15	15.797	2.09
14	5.96	0.24	1053.279	15.24	7.268	0.90	2.720	0.14	15.510	1.95
10	5.92	0.18	1044.874	9.64	7.211	0.92	2.677	0.13	15.130	1.78
7	5.85	0.17	1016.881	26.75	7.168	0.93	2.645	0.12	14.847	1.66

*Standard deviation.

of the materials. But the drag coefficients were not affected significantly by moisture content of wheat and *Turgenia latifolia* seeds (Table 1). This was due to the fact that the parameters associated with Eq. (1) increased along with each other as moisture content increased. Therefore, the drag coefficient of seeds did not significantly change over this range of moisture contents. These results are in agreement with some published literature. Afonso *et al*. (2007) reported that the drag coefficient of coffee cherries (cv. Catual) decreased from 0.05 to 0.03 as moisture content increased from 10.7 to 53.9% w.b. Gupta (2007), Irtwange and Ugbeka (2003) reported similar results for sunflower seed and African yam bean (cv. TSS 138), respectively. However, some odd results have been reported for some products. Irtwange and Ugbeka (2003) reported that the drag coefficient of African yam bean (cv. TSS 137) increased as moisture content increased from 4 to 16% w.b. Afonso *et al*. (2007) showed that the drag coefficient of coffee beans (cv Catual), coffee cherries and beans (cv. Conilon) increased as moisture content increased. Hauhouot *et al*. (2000) reported that the drag coefficient of wheat is 0.74.

CONCLUSIONS

1. The V_t value of wheat kernels was higher than those of *Turgenia latifolia* seeds and the difference between the maximum V_t of *Turgenia latifolia* seeds and minimum V_t of wheat kernels was about 1.5 m s^{-1}. Therefore, *Turgenia latifolia* seeds can be separated from wheat kernels successfully if the air velocity value is adjusted according to the V_t of *Turgenia latifolia* seeds.

2. In a milling plant separation can be performed either as a primary or secondary operation after the moisture content of the kernels has been increased through humidification. The V_t values of wheat increased for an increase in moisture content while the V_t values of the *Turgenia latifolia* seeds remained approximately the same for an increase in moisture content. Therefore, the maximum difference between the V_t values of wheat and *Turgenia latifolia* would be found in the secondary separation process. Consequently, a more efficient separation process of *Turgenia latifolia* from wheat would be done in the secondary operation in practice.

3. There were significant differences between the drag coefficients of wheat and *Turgenia latifolia* seeds at both grades, however, the drag coefficients of both wheat and *Turgenia latifolia* seeds were not affected by moisture content. Generally, to predict the V_t values of seeds by calculation method and related equations at any moisture content levels, it is advisable to use unique average values of drag coefficients of seeds at the studied moisture content levels.

REFERENCES

Afonso Jr. P.C., Correa P.C., Pinto F.A.C., and Queiroz D.M., 2007. Aerodynamic properties of coffee cherries and beans. Biosystems Eng., 98, 39-46.

Al-Mahasneh M.A. and Rababa T.M., 2007. Effect of moisture content on some physical properties of green wheat. J. Food Eng., 79, 1407-1473.

ASAE, **1998.** ASAE Standards. St. Joseph, MI, USA.

Baryeh E.A., 2002. Physical properties of millet. J. Food Eng., 51, 39-46.

Chakraverty A. and Paul S.R., 2001. Post Harvest Technology: Cereals, Pulses and Vegetables. Sci. Publ., India.

Gupta R.K., Arora G., and Sharma R., 2007. Aerodynamic properties of sunflower seed (*Helianthus annuus* L.). J. Food Eng., 79, 899-904.

Hauhouot O.M., Criner B.R., Brusewitz G.H., and Solie J.B., 2000. Selected physical characteristics and aerodynamic properties of cheat seed for the separation from wheat. Agric. Eng. Int., 2, 1-14.

Irtwange S.V. and Ugbeka J.C., 2003. Effect of accession and moisture content on aerodynamic properties of African yam bean (*Sphenostylis Stenocarpa*). Appl. Eng. Agric., 19(3), 321-328.

Jha S.N. and Kachru R.P., 2007. Physical and aerodynamic properties of makhana. J. Food Proces. Eng., 21, 301-316.

Khoshtaghaza M.H. and Mehdizadeh R., 2006. Aerodynamic properties of wheat kernel and straw materials. Agric. Eng. Int., CIGR Ejournal, 8, 1-10.

Kram B. and Szot B., 1999. Aerodynamic and geometric properties of amaranth seeds. Int. Agrophysics, 13, 227-232.

Mohsenin N.N., 1978. Physical Properties of Plant and Animal Materials. Gordon Breach Sci. Press, New York, USA.

Omobuwajo T.O., Akande E.A., and Sanni L.A., 1999. Selected physical, mechanical and aerodynamic properties of African breadfruit (*Treculia africana*) seeds. J. Food Eng., 40, 241-244.

Ozguven F. and Vursavus K., 2005. Some physical, mechanical and aerodynamic properties of pine (*Pinus pinea*) nuts. J. Food Eng., 68, 191-196.

Razavi S.M.A., Rafe A., and Akbari R., 2007. Terminal velocity of pistachio nut and its kernel as affected by moisture content and variety. African J. Agric. Res., 2(12), 663-666.

Tabak S. and Wolf D., 1998. Aerodynamic properties of cottonseeds. J. Agric. Eng. Res., 70, 257-265.

Zewdu A.D., 2007. Aerodynamic properties of tef grain and straw material. Biosystems Eng., 98, 304-309.