

Study of the effect of moisture on terminal velocity of the grain in some common paddy rice varieties in Iran

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Abstract:

Grain terminal velocity (TV) is one of the aerodynamic properties of the grain that plays a key role in the design of transfer and separation of mix of materials machines. In this study, this element was calculated theoretically in three varieties of rice husk (Khazar, Hashemi and Hybrid) in terms of grain moisture content (10, 14, 18 and 22% w.b.) and then was analyzed and evaluated. The results showed that Hashemi and Hybrid, respectively, have the most (10.832 m/s) and the least (9.816 m/s) mean values in grain TV. By changing the grain moisture content from 10 to 22% w.b., the mean TV increased significantly from 9.228 m/s to 11.336 m/s. The highest amount of average TV (12.245 m/s) was obtained in tests with Hashemi moisture content of 22% w.b. and the lowest (9.128 m/s) in the tests with Khazar variety with a moisture content of 10% w.b.

Keywords: Terminal Velocity, paddy rice

Introduction

One of the important parameters of physical properties of grain crops is TV. This parameter is of great importance in the design of the cleaning units, threshers, combines, and cleaning equipments.

When a particle falls by its own weight, its velocity is high enough to reach the final and fixed limit. In this case, particle weight force (W), drag force exerted on the particle (F_d), plus lifting force (F_L) are balanced and the particle has a uniform speed and its acceleration is zero (Mohsenin, 1978). In this case, by applying Newton's second law:

$$\Sigma F = ma = m \times 0 = 0$$

$$F_d + F_L - W = 0$$

$$F_d = W - F_L \quad (1)$$

Lifting force (F_d) is equivalent to the weight of the fluid volume of the grain:

$$F_L = \rho_a V g = \rho_a \frac{m}{\rho_p} g \quad (2)$$

In this relationship, ρ_a is the density of air (kg/m^3), m is particle mass (Kg), ρ_p is particle density (kg/m^3), and g is acceleration of gravity (m/s^2).

The tensile force acting on a particle is a resistant force imposed from air on the particle, prevents its movement, and is obtained from the following equation (Mohsenin, 1978):

$$F_d = \frac{1}{2} C_D \rho_a A (V_a - V_p)^2 \quad (3)$$

In the recent relation, C_D is drag coefficient (dimensionless), ρ_a is density of air (kg/m^3), A is the cross-section of the particle placed against the air stream perpendicular to the direction of air flow (m^2), V_p and V_a are, respectively, air and particle velocity (m/s). This means that drag force is proportional to the square of the relative velocity of the particle (relative to air velocity) while air is stagnant ($V_a=0$) and the particle falls under the influence of its own weight and, then in the balance state, its speed reaches velocity (V_t) is then:

$$F_d = \frac{1}{2} C_D \rho_a A V_t^2 \quad (4)$$

By putting the second party, relationships (2) and (3) in equation (1), we have:

$$\frac{1}{2} C_D \rho_a A V_t^2 = mg - \rho_a \frac{m}{\rho_p} g$$

$$\frac{1}{2} C_D \rho_a A V_t^2 = mg \left(1 - \frac{\rho_a}{\rho_p} \right)$$

and or

$$V_t = \left[\frac{2mg(\rho_p - \rho_a)}{C_D A \rho_a \rho_p} \right]^{\frac{1}{2}} \quad (5)$$

To determine the velocity of a particle, usually all parameters except coefficient of drag (CD) are known. This coefficient is obtained from the following equation (Mohsenin, 1978):

$$C_D = \frac{2C}{R_e} \quad (6)$$

Where (C) is particle shape factor (dimensionless), and R_e is Reynolds number (dimensionless). Shape factor for oval cross-section particles is obtained from the following equations:

$$C = \frac{(a.b.c)^{\frac{1}{3}}}{a} \quad (7)$$

In this formula, a, b, and c are, respectively, large, medium and small diameters of the particles (m), Reynolds number that is the ratio of inertial effects to statement of viscosity fluid is calculated by the following formula:

$$R_e = \frac{\rho l U}{\mu} \quad (8)$$

In this relationship, ρ is density or density of the fluid (air) (kg/m^3), l is the length of object (m), U is fluid velocity (m/s), and μ is viscosity of fluid (N. S/m^2). In this relationship, to determine R_e , the fluid velocity should be known that in many cases is unknown. In this case, to determine the (R_e), first $C D R_e^2$ is calculated by the following equation and then by referring to the diagram (Figure 1), Reynolds number is determined (Mohsenin, 1978):

$$C_D R_e^2 = \frac{4g \rho_a d_g^3 (\rho_p - \rho_a)}{3\mu^2} \quad (9)$$

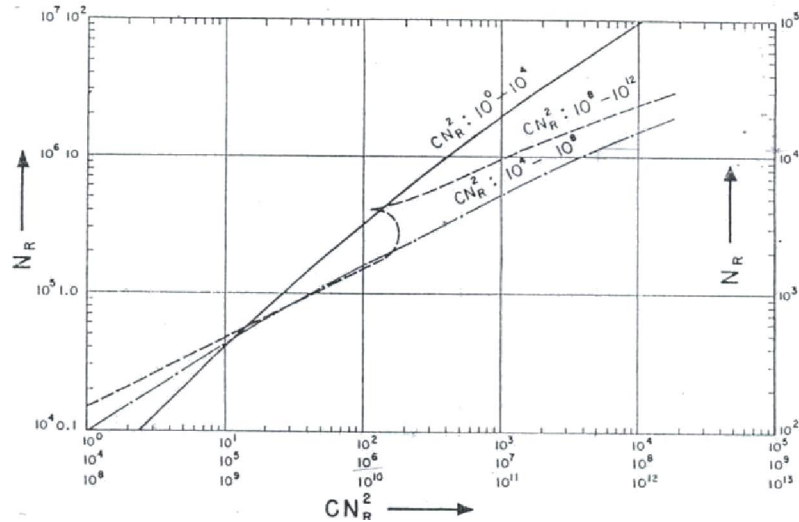


Figure 1: Relations between $CDRe^2$ with Re (Mohsenin, 1978)

d_g Is geometric mean of particle diameter (grain), that is:

$$d_g = (abc)^{1/3} \quad (10)$$

By determining Reynolds number and calculating the amount and form factor for a particular seed, the speed limit of it is obtained from Equation (5).

One of the aerodynamic features of crops is TV that plays an important role in the design of machines for cleaning and separating grain from material other than grain and conveying equipment. Many studies have been conducted to determine TV and the impact of moisture content of the product on it different products. Two et al. (1999) examined aerodynamics features of rice husk in two Hindi varieties studied in terms of moisture. The results showed that the effect of increasing humidity on velocity has been significant and one variety with its increase from 11.2 to 20.5%, TV increases from 6 m/s to 6.2, and in the other variety with its change from 11.4 to 19.8%, TV has varied from 5.6 m/s to 5.8. To determine and evaluate TV of grain of different products, Bilanski et al. (1962) have used a rated glass tube with a diameter of 2 ft (60.96 cm).

In these tubes, the grains at different heights were released with zero initial speed and then falling time was recorded by gauges. Then, collected data points were transported to coordinate such as the longitudinal axis time (s) and in the transverse axis, distance or height of falling. By combination of different points, the curve was obtained whose slope shows the TV of the grain. In this way, TV of wheat was obtained as 4.71 m/s. Bilanski and Lal (1964) determined TV of grain in an experimental method (using wind tunnel) equivalent to 8.64 m/s. Shamsabadi (2001) examined traction and TV of beans, corn, barley, and lentils theoretically (using equations and formulas), and examined TV and traction of oats, maize and lentils.

In examining the aerodynamic properties of wheat (Canadian variety), Khoshtagaza and Mehdi Zadeh (2006) concluded that by increasing the moisture content of the grain from 7 to 20% (wb), grain TV changes from 6.81 to 8.63 m/s linearly. Many researchers such as (Sotar and Das, 1996), (Joshi et al., 1993), (Dutta et al., 1988), Gobeta and Prakash, 1992) and (Aryara et al., 2005) have studied the physical properties of different agricultural products, particularly TV of grain. By reviewing these resources, it is shown that studying physical and mechanical properties of grain, particularly rice due to its immense production and consumption in the country and the world is of great importance. In this study, TV rate of seeds in different varieties of rice as husk, depending on the grain moisture content has been analyzed.

Materials and methods

The varieties used in these experiments (Khazar, Hashemi and Hybrid) were obtained from the Rice Research Institute. Grains were manually cleaned to remove any excess material, peat pellets and broken grains were separated from them. The initial moisture of the grains was determined by moisture meter with digital devices model GMK-303. In order to prepare samples with needed moisture in experiments at 4 moisture levels of 10, 14, 18 and 22% wb, using the formula of the amount of water needed to be in the sample will be added to the moisture levels tested they were calculated (Mohsenin, 1978).

$$w_i \left(1 - \frac{m_i}{100}\right) = w_f \left(1 - \frac{m_f}{100}\right) \quad (11)$$

$$w_i + w_i = w_w \quad (12)$$

Where:

w_i = Weight of initial moisture content (gr)

w_f = Weight of the product with final moisture content (gr)

w_w = Weight of water added to the product (gr)

m_i = Initial moisture content wb

m_f = The final moisture content wb

Water needed was added to seeds and thoroughly mixed. The water required for weight was added to the grains, mixed, placed in plastic bags, blocked, and kept for two days in a refrigerator at a temperature of 10 ° C to reach optimum and uniform moisture levels (Reddy and Chakraverty, 2004).

Shortly before the start of measurements in order to even the temperature of samples to test environment, samples were removed from the fridge and placed in experiment environment. From each sample, 10 samples were selected randomly and grain physical characteristics including length, width, and thickness were measured at each moisture level.

The following steps were used to determine TV of each grain (Mohsenin, 1978):

- 1- The geometric mean of grain diameters (d_g) was calculated from equation (6).
- 2- Evectional area perpendicular to the air flow direction (A_g) was determined by the following formula:

$$A_g = \frac{\pi}{4} d_g^2 \quad (13)$$

3- The following formula was used to calculate the volume of grain (Vg):

$$V_g = \frac{\pi}{6} d_g^3 \quad (14)$$

4- The particle density (ρ_g) was calculated by the following equation:

$$\rho_g = \frac{m_g}{V_g} \quad (15)$$

5- $CDRe^2$ was calculated from equation (9).

6- By referring to Figure 1, Reynolds number (Re) and thus (Cd) were determined.

7- TV was calculated by equation (9)

To calculate TV, density and temperature of air was 21°C, equivalent to (1.2 kg/m³) and its viscosity was considered (18.098×10⁻⁷ N.s/m²) (Mohsenin, 1978).

Given the number of varieties tested (3 varieties), grain moisture content levels (4 levels), and the number of repetitions (10), 120 data were obtained for analysis.

Analysis of data obtained was done using factorial in a randomized complete block design, and to compare the effects and interactions of autonomous agents (variety and humidity), Duncan's multiple range test (level of 5%) was used. Data analysis was performed using MSTATC software.

Results and discussion

Summary of analysis of variance data is given in Table 1:

Table 1: Analysis of variance of data related to TV in rice varieties tested

Sources of changes	Degrees of freedom (DF)	Mean Square (MS)	F ratio
Repeat	9	0.003	0.7820 ns
Variety (V)	2	10.333	**2599.2297
Moisture (M)	3	28.578	**7187.4667
Interactions (M×V)	6	1.808	**454.8840
Error	99	1.004	

** Significant at 1% and ns no significant effect

Results of statistical analysis of the data showed that the main effects of variety, moisture, and interaction of these two factors on rice husk has been significant ($p = 1$ percent). The results of comparison of the average main effects and humidity (Table 2) showed that the mean TV of all varieties tested ($p=5\%$) has significant differences. The highest amount of average velocity (10.832 m/s) was for Hashemi and the lowest average (9.816 m/s) to Hybrid. With increase in moisture content of grain from 10 to 22% w.b., average TV has had a significant increased from 9.228 m/s to 11.368 m/s.

Table 2: A comparison of the main effects of the average grain moisture content and the velocity (m / s)

Varieties tested and their average effects		Grain moisture content levels (w.b.%) and the average of them	
Khazar	10.341b	10	9.228d
Hashemi	10.832a	14	9.830c
Hybrid	9.816c	18	10.892b
		22	11.368a

Dissimilar letters in each column indicate a significant difference between the effects of (5%).

The result of this is completely consistent with the studies conducted by many researchers (Tado, et al., 1999 Bilanski, et al., 1965, Gupta and Prakash, 1992, Aviara et al., 2005, khoshtagaza and Mehdizadeh, 2006).

The reason is that with an increase in moisture content, weight and thus its density increases, and according to equation (5) TV of the grain increase. The results of the comparison of interaction effects and the grain moisture content (Figure 2) showed that in all varieties with increased grain moisture content from 10 to 22% w.b., there has been a significant increase in grain TV.

In experiments with Khazar variety, by changing moisture content from 10 to 22% w.b. TV of the grain changes from 9.128 m/s to 11.432m/s, in experimenting with Hashemi from 9.302 m/s to 12.245 m/s, and in experimenting with Hybrids from 9.245 m/s to 10.427 m/s with significant changes. In other words, TV changes in Khazar, Hashemi and Hybrid has been, respectively, 21%, 24% and 11.34%.

Linear equation linear VT terms of moisture content in different rice varieties tested is as follows:

Khazar Variety $R^2 = 0.909$
 $V_t = 0.856M + 8.201$

Hashemi Variety $R^2 = 0.995$
 $V_t = 0.966M + 8.417$

Hybrid variety $R^2 = 0.949$
 $V_t = 0.423M + 8.759$

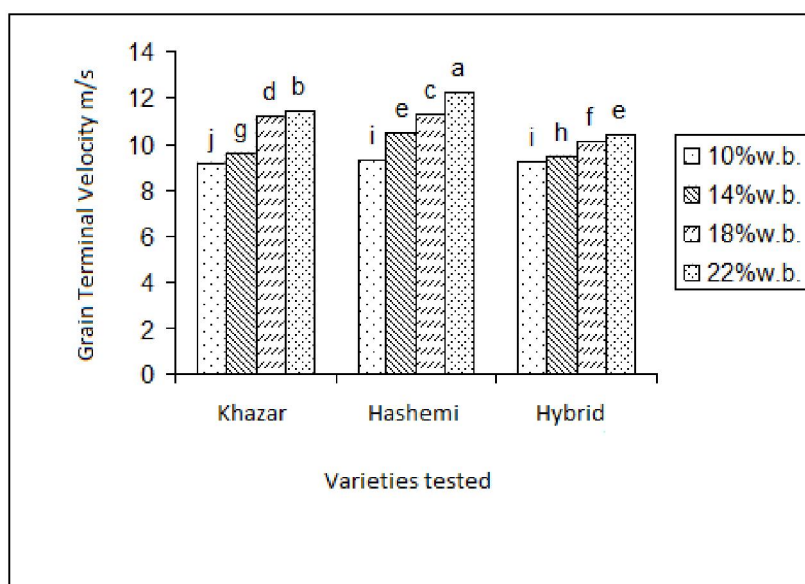


Figure 2: A comparison of the average effect of interaction and grain moisture on TV

By comparing the coefficient of determination (R^2) for regression equations in different varieties, it is seen that linear regression equation of TV related to Hashemi has the highest coefficient of determination ($R^2=0.995$).

Conclusion

1. TV in tested cultivars (Khazar, Hashemi and Hybrid) is very different, so that Hashemi and Hybrid, respectively, have the

highest (10.832 m/s) and the lowest (9.816 m/s) mean value of the grain terminal velocity.

2. By changing the grain moisture content from 10 to 22% w.b., the average TV has had significant increased from 9.228 m/s to 11.368 m/s.
3. The maximum amount of average TV (12.245 m/s) was in tests with Hashemi with moisture content 22% w.b. and minimum (9.128 m/s) in the tests with Khazar variety with a moisture content of 10% w.b.
4. Change in grain TV in terms of grain moisture content from 10 to 22% w.b. in the tested cultivars linear coefficient of determination (R^2) more than 0.90, so that the highest amount ($R^2=0.995$) is dedicated to Hashemi.

دراسة تأثير الرطوبة على معدل حجم الحبوب في بعض الأصناف الشائعة من قشر الأرز في إيران

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المخلص:

سرعة حجم الحبة إحدى الخصائص الهوائية للحبوب التي تلعب دوراً أساسياً في تصميم آلات النقل وفصل الخليط من المواد. عولجت في هذا البحث نفس العامل في ثلاثة أنواع من الأرز (خزر، هاشمي وهيريدي) على حسب محتوى رطوبة الحبوب نظرياً ثم تم تحليلها و تقييمها. أظهرت نتائج هذا البحث أن نوعي هاشمي وهيريدي متوالين لديهما أعلى ($10/832$ m/s) وأقل ($9/816$ m/s) كمية معدل سرعة الحبوب. مع التغيير في تغيير محتوى رطوبة الحبة من 10 إلى 22% w.b.، زيد معدل سرعة حجم من $9/228$ m/s إلى $11/368$ m/s. أعلى كمية معدل سرعة الحجم ($12/245$ m/s) في اختبارات صنف هاشمي بمحتوى الرطوبة w.b. 22% وأقل كمية معدلها ($9/128$ m/s) في اختبارات صنف خزر بمحتوى الرطوبة w.b. 10%.

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