

Determination of dynamic friction coefficient of paddy grains on different surfaces

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A b s t r a c t. An apparatus developed for measurement of dynamic friction coefficient is presented. The dynamic friction coefficient of paddy grains was determined and studied in three varieties (Alikazemy, Hashemi and Khazar), at two levels of moisture content (12 and 23% w.b.), three levels of peripheral speed (0.5, 3.5 and 6.5 cm s⁻¹) and on three contact surfaces (black, mild and galvanized sheets). The experiments were arranged as a split-split plot fitted into randomized complete block. The results of variance analysis revealed that the effects of grain moisture content, variety, contact surface, peripheral speed and their interactions were significant ($p < 0.01$) on dynamic friction coefficient. With increase in the moisture content of grain and peripheral speed of disc, dynamic friction coefficient increased. Among the contact surfaces, the highest and lowest values of dynamic friction coefficient were 0.567 and 0.314 and belonged to the black and galvanized sheets, respectively. Also, among the varieties, Alikazemi and Khazar varieties had the maximum and minimum mean values, respectively.

K e y w o r d s: physical properties, paddy, contact surface, dynamic friction coefficient

INTRODUCTION

Cereals are the most important food products in the world. Among cereals, after wheat, rice is cultivated on the most extensive area of cultivated lands in the world. Today in Iran, the cultivated area of rice is about 615 000 ha (Askari Asli-Ardeh and Abbaspour-Gilandeh, 2008). Among cereals, rice constitutes the basic food for great numbers of human beings.

Static and dynamic friction coefficients of grains on various surfaces are needed for designing agricultural crop storage structures, handling and transporting equipments, such as belt and screw conveyers, and also needed in order to determine yield milling and post harvesting equipments (Bickert and Buelow, 1966; Mohsenin, 1980; Sitkei, 1986).

The effect of various factors on coefficient of friction has been investigated by several workers (Ghasemi Varnamkhasti *et al.*, 2007; Joshi *et al.*, 1993; Molenda *et al.*, 2000; Shepherd and Bhardwaj, 1986; Synder *et al.*, 1967). Many researchers, determining the static and dynamic friction coefficients of agricultural materials, have observed an increase in dynamic friction coefficients with an increase in moisture content (Coskoner and Karababa, 2006; Kappuswamy and Wratten, 1970; Kashaninejad and Rezaghah, 2007). Gupta and Das (1998) reported that dynamic friction coefficients of sun flower seed increased linearly with increase in the moisture content, irrespective of the nature of the surfaces. Chung and Verma (1998) reported that the effect of moisture content was found to be more pronounced on coefficient of static friction than coefficient of dynamic friction for soy bean, red kidney bean and peanut. The results of this research showed that the surface material has a greater effect on dynamic friction coefficient than on the coefficient of static friction. Kappuswamy and Wratten (1970) in their experiments aimed at determination of static and dynamic friction coefficients of paddy grains observed that the coefficient of dynamic friction increased generally with increase in velocity at all moisture content.

The effect of grain moisture content, contact surface and peripheral speed of the sample grains on dynamic friction coefficient of paddy grains was investigated using the designed apparatus.

MATERIALS AND METHODS

An apparatus was designed and constructed to determine the dynamic friction coefficient of paddy grains. It consisted of a sample holder that was supported by a solid aluminium rod of 13 mm diameter. The aluminium rod maintained the

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sample holder in a horizontal position above and parallel to a rotating disc. The disc was rotated by an electro-motor. An inverter was applied to verify the peripheral speed of rotating disc. The end of the aluminium rod was bolted to a supporting frame. The sample holder was made of two PVC cylinders with inner diameters of 110 and 200 mm. The height of the cylinders was 56 mm. The space between the two cylinders was equally divided by three baffle plates. These plates prevented the grain sample from rotation with the rotating disc. Different contact surfaces were fixed on the disc. The clearance between the rotating disc and the bottom of the cylinders (0.3-0.5 mm) was adjusted with vertical movement of the sample holder and the fastening of the bolts. This was arranged such that the sample holder had no contact with the test surfaces. The rotational movement of the disc imparted torque motion to the sample holder and then to the aluminium rod via the sample. While a normal force acted between the sample and the test surface, the vertical plates resisted any tendency of the sample to rotate with the disc. Thus the net force exerted a torque on the supporting aluminium rod. For determining the torsion torque, four strain gauges, each with a resistance of 120 and gauge factor of 2, were attached on the aluminium rod and aligned at 45° with the central axis. The strain gauges were connected to a Wheatstone-bridge circuit and data were recorded by a DT800 data logger which was connected to a personal computer. The frequency of data taking was 1 datum in each 5 s and data were recorded online within 1.5 min. The apparatus was calibrated by applying known forces to the aluminium rod through a torque arm with known length. In order to prevent device vibration, weights were used on the frame of the apparatus.

Three varieties of paddy grain (Alikazemi, Hashemi and Khazar) were used (obtained from the Rice Research Institute, Gilan, Iran). The grains were manually cleaned to remove all foreign matter such as dust, chaff, immature and broken grains. The initial moisture content of the grains was determined with a digital moisture meter model GMK-303.

In order to obtain samples with desired moisture content, immediately after harvesting (with moisture content of 25% w.b.), the amount of water (distilled) required to provide the needed moisture content of grain was calculated by the following equations, and then added to the grain and mixed thoroughly. The equations used are (Chakraverty and Singh, 2002):

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

$$w_w = w_f - w_i, \quad (2)$$

where: m_i – initial moisture content of sample (% w.b.), m_f – final moisture content of sample (% w.b.), w_i – initial mass of sample (g), w_f – final mass of sample (g), w_w – mass of water added to sample (g).

The samples were then poured into separate polyethylene bags and the bags were sealed tightly. The samples were kept at 10°C in a refrigerator for 2 days to enable the moisture to distribute uniformly throughout the sample (Reddy and Chakraverty, 2004). For accomplishing the tests, 350 g of the grains were evenly distributed in each division compartment of the sample holder.

The torque which was transferred to the aluminium rod due to the effect of friction force between paddy grains and contact surface was calculated by the following equations and the free diagram (Fig. 1):

$$dF = \mu dN, \quad (3)$$

$$N = \gamma V, \quad (4)$$

$$dT = r dF = r \mu \gamma h r dr d\theta, \quad (5)$$

$$\gamma = \rho g = \frac{W}{h\pi(R_0^2 - R_i^2)}, \quad (6)$$

$$T = \mu \frac{W}{\pi(R_0^2 - R_i^2)} \int_0^{2\pi} \int_{R_1}^{R_0} r r dr d\theta, \quad (7)$$

$$T = \frac{2\mu W}{(R_0^2 - R_i^2)} \left[\frac{R_0^3}{3} - \frac{R_i^3}{3} \right] \Rightarrow Q = \frac{2}{3} \left[\frac{R_0^3}{R_0^2} - \frac{R_i^3}{R_i^2} \right], \quad (8)$$

where: μ – coefficient of friction (-), T – measured torque (N m), W – total sample weight on the rotating surface (N), Q – effective torque arm (m), R_0 – inner radius of the outer cylinder of the sample holder (m), R_i – inner radius of small cylinder of the sample holder (m), h – height of cylinder of the sample holder (m), γ – specific weight of paddy grain (N m⁻³), V – volume of cylinder of the sample holder (m³), N – vertical force on rotating disc (N), $g = 9.81$ (m s⁻²), ρ – mass of a unit volume of paddy grain (kg m⁻³).

Finally, the coefficient of dynamic friction was obtained by using an average of 18 recorded data by data logger within 1.5 min and the following equation:

$$\mu = \frac{T}{WQ}. \quad (9)$$

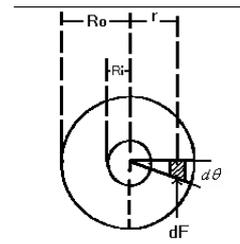


Fig. 1. Free diagram of force exerted on sample holder by rotating disc.

The experiments were accomplished in three replications. Thus, by attention to the level of moisture (2 levels), the number of varieties (3 varieties), the number of levels of peripheral speed (3 levels) and the number of contact surfaces (3 surfaces), 162 experiments were performed. The obtained data were analyzed by split-split plot test based on complete randomized block. The mean effects were compared by using Duncan's Multiple Rang Test with ($p < 0.05$). For analysing the variance of data, the MSTATC package was applied.

RESULTS AND DISCUSSION

A summary of the results of the dynamic friction coefficient (DFC) determination is displayed in Table 1. The results showed that the main effects of moisture content, variety, contact surface, velocity and also their interactions on

dynamic friction coefficient were significant ($p < 0.01$). This was because of the various qualities of grains in various varieties and also of the different quality of the contact surfaces. Also with increase in moisture content of grains, because of increasing adhesion force, the dynamic friction coefficient was increased significantly.

The results of mean comparison of main effects on dynamic friction coefficient are displayed in Table 2. The results showed that with increase in moisture content of grains and surface velocity, the dynamic friction coefficient increased significantly. Among the contact surfaces, the highest (0.567) and lowest (0.314) of dynamic friction coefficient mean values belong to black and galvanized sheets, respectively. Also, among varieties, the maximum (0.441) and minimum (0.408) of dynamic friction coefficient mean values were determined for Alikazemi and Khazar, respectively ($p < 0.05$).

Table 1. Results of variance analysis

Source	Degree of freedom	Sum of squares	Mean square	F value
Replication	2	0.001	0.000	4.3038 ^{ns}
Moisture content (M)	1	0.347	0.347	3457.2749 ^{**}
Error	2	0.000	0.000	
Variety (V)	2	0.030	0.015	27.0293 ^{**}
(M. C. × V)	2	0.087	0.043	77.0541 ^{**}
Error	8	0.004	0.001	
Contact Surface (C.S.)	2	1.803	0.902	1118.6155 ^{**}
(M. C. × C. S.)	2	0.032	0.016	19.9689 ^{**}
(V × C. S.)	4	0.398	0.099	123.3033 ^{**}
(M. C. × V × C. S.)	4	0.083	0.021	25.6335 ^{**}
Surface Velocity (S.V.)	2	1.264	0.632	748.1186 ^{**}
(M. C. × S. V.)	2	0.014	0.007	7.8085 ^{**}
(V × S. V.)	4	0.032	0.008	9.8369 ^{**}
(M.C. × V. × S. V.)	4	0.014	0.004	4.4576 ^{**}
(C. S. × S. V.)	4	0.015	0.004	4.6530 ^{**}
(M.C. × C. S. × S. V.)	4	0.005	0.001	1.6155 ^{ns}
(V × C. S. × S. V.)	8	0.067	0.008	10.3723 ^{**}
(M. C. × V. × C. S. × S. V.)	8	0.026	0.003	3.9883 ^{**}
Error	96	0.077	0.001	
Total	161	4.300		

^{**}Significant at less than 1% probability level, ns – not significant.

Table 2. Result of mean comparison of the main factors affecting the dynamic friction coefficient

Moisture content		Variety		Contact surface		Surface velocity	
23 (% w.b.)	0.472 a*	Alikazemi	0.441 a	Galvanized	0.314 c	0.5 cm s ⁻¹	0.315 c
12 (% w.b.)	0.380 b	Hashemi	0.429 a	Mild	0.396 b	3.5 cm s ⁻¹	0.431 b
		Khazar	0.408 b	Black	0.567 a	6.5 cm s ⁻¹	0.531 a

*Different letters show significant differences at probability level of 5%.

The results of the mean comparison of the interaction effects of moisture content and contact surface (Fig. 2) showed that for all surfaces the dynamic friction coefficient increased significantly with increase in moisture content. This result was similar to the results obtained by Kappuswamy and Wratten (1970) and also Gupta and Das (1998). The obtained highest mean value (0.631) of the dynamic friction coefficient belonged to black sheet surface at a moisture content of 23% w.b.

The results of mean comparison of the interaction effects of moisture content and variety (Fig. 3) showed that in all varieties the dynamic friction coefficient was increased significantly with increase in the moisture content. The highest mean value of the dynamic friction coefficient (0.508) among the varieties was obtained for the Hashemy variety at moisture content of 23% w.b.

The results of mean comparison of interaction effects of variety and contact surface (Fig. 4) showed that the lowest (0.236) and highest (0.637) mean values of dynamic friction coefficient were those of the Alikazemi variety on galvanized sheet and black sheet contact surface, respectively. And also, for the Hashemi and Khazar varieties there were no significant differences in the dynamic friction coefficient mean values on galvanized and mild surfaces.

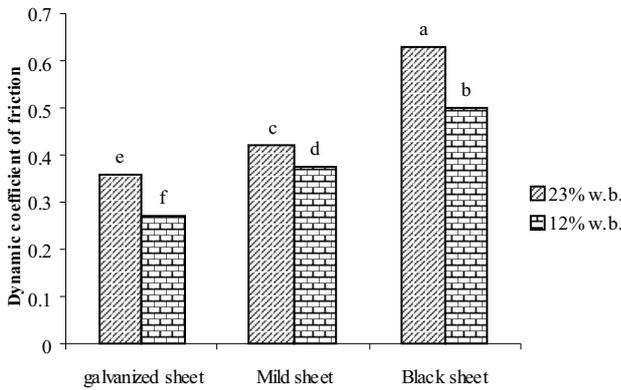


Fig. 2. Results of mean comparison of interaction effects of moisture content and contact surface. Explanations as in Table 2.

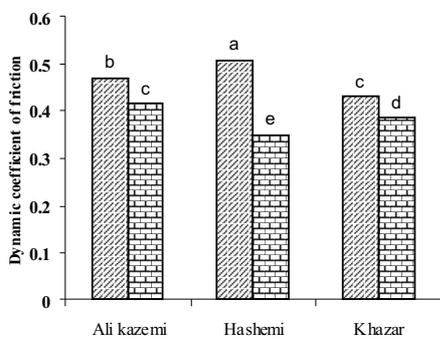


Fig. 3. Results of mean comparison of interaction effects of moisture content and variety on dynamic coefficient of friction. Explanations as in Table 2 and Fig. 1.

The results of mean comparison of the interaction effects of moisture content and surface velocity on dynamic coefficient of friction are shown in Fig. 5. The results showed that with increasing velocity, at each two levels of grain moisture content, dynamic friction coefficient increased significantly. And also, the results showed that the highest mean value of dynamic friction coefficient (0.569) was obtained for surface velocity of 6.5 cm s⁻¹ at moisture content of 23% w.b.

The results of mean comparison of interaction effects of variety and surface velocity on dynamic friction coefficient are shown in Fig. 6. The results showed that in all varieties the dynamic friction coefficient values increased significantly with increasing surface velocity. Among the varieties the highest mean value of the dynamic friction coefficient (0.542) belongs to Hashemi variety.

The results of mean comparison of interaction effects of contact surface and surface velocity (Fig. 7) showed that on all contact surfaces the dynamic friction coefficient increased significantly with increase in surface velocity. The highest value of the dynamic friction coefficient (0.661) was recorded for the black sheet surface at surface velocity of 6.5 cm s⁻¹.

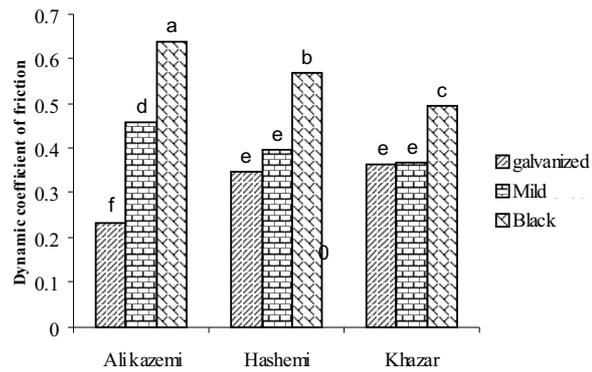


Fig. 4. Results of mean comparison of interaction effects of variety and contact surface on dynamic coefficient of friction. Explanations as in Table 2.

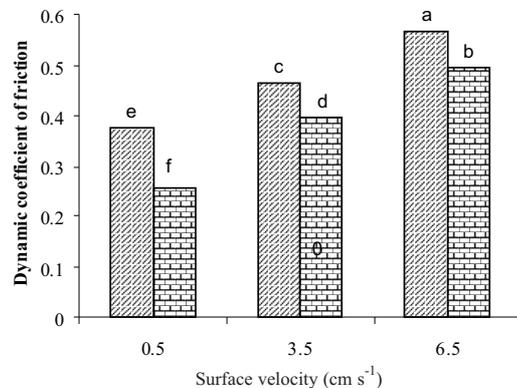


Fig. 5. Results of mean comparison of interaction effects of moisture content and surface velocity on dynamic coefficient of friction. Explanations as in Table 2 and Fig. 1.

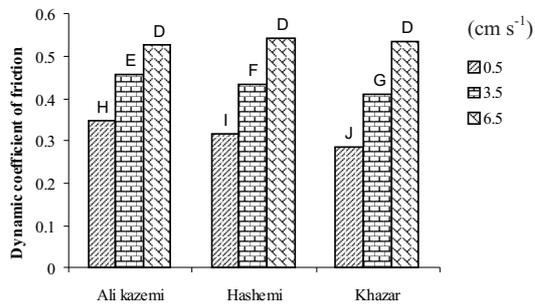


Fig. 6. Results of mean comparison of interaction effects of variety and surface velocity on dynamic coefficient of friction. Explanations as in Table 2.

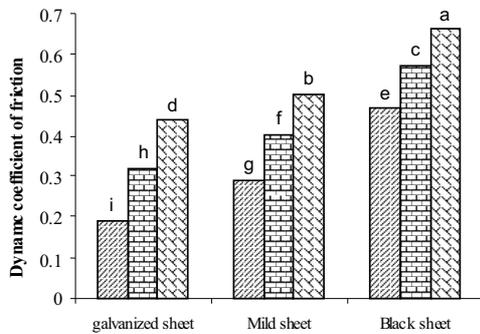


Fig. 7. Results of mean comparison of interaction effects of contact surface and surface velocity on dynamic coefficient of friction. Explanations as in Table 2 and Fig. 5.

CONCLUSIONS

1. With increase in moisture content of paddy grain from 12 to 23% w.b., dynamic friction coefficient increased significantly from 0.380 to 0.472.
2. Among tested varieties, the lowest (0.408) and the highest (0.441) mean values of dynamic friction coefficient were obtained for the Khazar and Alikasemi varieties, respectively.
3. Among the tested contact surfaces, the lowest (0.314) and the highest (0.567) mean values of dynamic friction coefficient were recorded for the galvanized and black sheets, respectively.

4. With the peripheral speed of contact surfaces varying from 0.5 to 6.5 cm s⁻¹, dynamic friction coefficient increased significantly from 0.315 to 0.531.

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