Determination of dynamic friction coefficient in common wheat varieties on different contact surfaces

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Abstract: Dynamic friction coefficients of agricultural crops are applied in designing silos, agricultural crops storage structures, transporting, handling machines and discharging implements. In this study, at first an apparatus for measuring dynamic friction force was developed, then the dynamic friction coefficient of common wheat varieties at five levels (*Azar*2, *Rasad, Sardari, Zagros, Sabalan*) were investigated on contact surface at four levels (black, galvanized, mild and aluminum sheets), with sample slipping speed at three levels (5, 10 and 15 cm s^{-1}) and grain moisture content at three levels (12%, 14% and 18% w. b.). The data were analyzed probability. The obtained results revealed that the main effects of all independent factors as well as the double interactions on the dynamic friction coefficient were significant (P<0.01). Also, the results revealed that with an increase in the grain moisture content from 12% to 18% w. b., the dynamic friction coefficient mean increased from 0.249 to 0.335. And also with an increase in the samples slipping speed from 5 to 15 cm s^{-1}, the dynamic friction coefficient increased significantly from 0.265 to 0.298. Among the contact surfaces, the highest mean value (0.331) and the lowest mean value (0.248) allocated to black and galvanized sheets, respectively. Also, among the varieties, the highest (0.299) and the lowest (0.273) mean values allocated to *Azar*2 and *Zagros* varieties, respectively.

Keywords: wheat grain, contact surface, moisture content, dynamic friction coefficient

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1 Introduction

Dynamic friction coefficient of cereals and other agricultural crops is required to design silos, agricultural crops storage structures, transporting devices such as belt conveyor and screw conveyors, and also it affects the performance of postharvest equipments (Sitkei, 1986). Dynamic friction coefficient is influenced by many factors such as product variety, grain moisture content, the material of contact surface and sliding velocity. The grain moisture content of the wheat is dictated by its suitability for long–term storage (Kibar, 2016). In an investigation about the effects of gain moisture, vertical pressure and sliding velocity on the static and dynamic friction coefficient, Thampson and Ross (1983) concluded that by increasing grain wheat moisture content from 8% to 20% w. b., friction coefficient increased, while at the grain moisture content of 24% and over, the friction coefficient decreased. Lawton and Marchant (1980) reported that the friction coefficient of grain wheat, barley and oat at the moisture content from 10% to 15% w. b., at first increases with less intensity and then at range of grain moisture content (15% to 22% w. b.) it quickly decreased. Finally, by increasing grain moisture content from 22% to 30 % w. b., the friction coefficient increased. In the determination of friction coefficient of coriander seeds on different surfaces, Coskuner and Karbaba (2006) observed that by increasing moisture content, the friction coefficient

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increased due to more roughness of the grains. According to the results by Chung et al., (1984), the material of contact surfaces affected more on the dynamic friction coefficient than static friction coefficient. Kappuswamy and Wratten (1970) concluded that by increasing sliding velocity at all tested moisture content levels, the dynamic friction coefficient increased. Gupta and Das (1998) observed a little change in dynamic friction coefficient by variation of sliding speed levels at tests with sunflower seeds. To determine the effect of sliding velocity on the dynamic friction coefficient of wheat grain, Thampson and Ross (1983) concluded that friction coefficient is significantly increased by changing sliding velocity. In the examination of the effect of various factors on the static and dynamic friction coefficient of pea on galvanized steel and black surfaces, Kermani (1998) found that the effect of grain moisture content on dynamic friction coefficient was significant and generally by increasing moisture content, the dynamic friction coefficient increased; however, on the galvanized steel surfaces at the moisture content of 21% w. b., the friction coefficient decreased. During determination of the dynamic friction coefficient of three paddy grain common varieties (*Ali Kazemi* , *Hashemi and Khazar*) on three surfaces (galvanized, mild and black sheets) in two moisture surfaces (12% and 23% w. b.) and at three speed levels (0.5, 3.5 and 6.5 cm s^{-1}), Askari Asli- Ardeh *et al.* (2009) found that by increasing the grain moisture content and sliding speed, the dynamic friction coefficient significantly increased and among tested surfaces, galvanized and black sheets had the lowest and the highest dynamic friction coefficients, respectively. Kibar and Öztürk, (2009) observed that dynamic coefficient of friction increased with increase in moisture content for hazelnut varieties. The highest value of the dynamic coefficient of friction was recorded in the Badem variety at 20% moisture content with a concrete surface (0.287), and the lowest value of the dynamic coefficient of friction was recorded in the Sivri variety at 8% moisture content with a galvanized steel surface (0.093). Gupta and Das (1998) reported that surface velocity between 0.09 and 0.29 m s^{-1} only had a small effect on dynmic coefficient of friction. Altuntas and Yildis (2007) detemined dynamic friction coefficient of faba beans grains with surface speed at 2 cm s^{-1}. Molenda et al., (2000) studied dynamic friction coefficient of wheat at a range of 0.05 to 50 mm s^{-1}. Among all researchs, the maximum movement speed of samples into box was limited because of the movement control of sample box. Thus, according to the test conditions in this research, the range of sample speed was selected from 5 to 15 cm s^{-1}. In addition, this study investigated the effects of contact surfaces, sliding speed of grain samples and grain moisture content on dynamic friction coefficient of some common grain wheat varieties.

2 Materials and methods

Equipments (Figure 1) required for measuring the dynamic friction coefficient included Electromotors gearbox model of ZA25 (12V, 200RPM, 1000A), power supply with ability to change voltage (1000 Ma, 3-12 V), digital dynamometer model (FGA, K5) made by Dacell Korea Company with the accuracy of 0.001 kg-f along with software, sample box including four wheels, personal computer, contact surfaces and a table for placing its related equipment. Dynamometer, electromotors and power supply were used to prepare sample tension force, sample box movement and the movement speed levels of sample box, respectively.

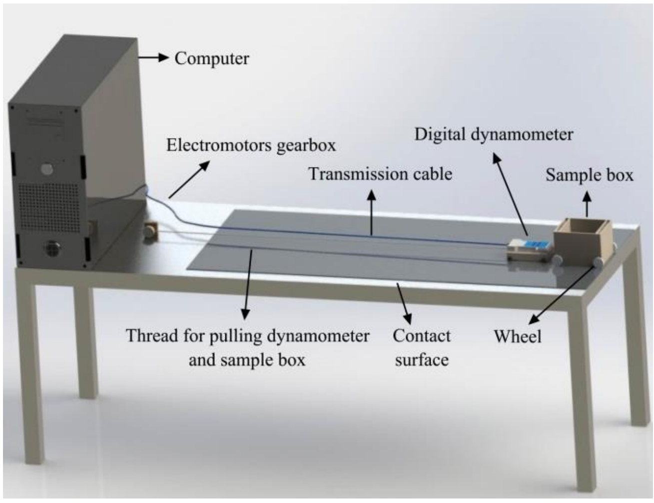

Figure 1 Equipments for measuring dynamic friction coefficient of wheat

Five tested grain wheat varieties (*Azar*2, *Rasad*, *Sardari*, *Zagros*, *Sabalan*) were obtained from Agricultural Research Center of Ardabil province. The tested grains were completely clean. First, the initial moisture content of the grains was determined using digital moisture meter GMK-303 model and samples were prepared with the required moisture content (12%, 14% and 18% w. b.) using following equations, the amount of distilled water required for supplying the grain moisture content was calculated by the following Equation (1) and (2) (Balasubramanian, 2001; Kibar and Öztürk, 2008):

$$W_i\left(1-\frac{m_i}{100}\right)=W_f\left(1-\frac{m_f}{100}\right) \quad (1)$$

$$W_i - W_f = W_w \quad (2)$$

where, W_i is the grain weight with the initial moisture content (g); W_f is the grain weight with the final moisture content (g); W_w is weight of added water (g); m is the percentage of initial grain sample weight; m_f is the percentage of final sample grain weight.

Then, the grain samples were put into a closed plastic bag and located in a refrigerator at 10 ℃ for five days to achieve the desired moisture levels (Gupta and Das., 1998). To determine the dynamic friction coefficient, the prepared samples were poured into the box and then, the box containing the samples was pulled on various contact surfaces at different fixed speed levels by electromotor gearbox. Simultaneously, the friction force (F) was measured by dynamometer and the data obtained were transferred and recorded in computer. To calculate the dynamic friction coefficient (μ), the data was transferred into excel software and using $\mu=(F/N)$, the value of dynamic friction coefficient was calculated in terms of sample weight (N). The tests were done with six replications. Before accomplishment of each test, tension force measured at no-load condition was subtracted from all the recorded force data at the load condition. A completely randomized design was used at data analysis. The data were obtained from tests and multiple-range Duncan's test was used to compare the main effects and interactions among independent factors (grain moisture content, variety, contact surface and sliding velocity).

3 Results and discussion

The results of the analysis of variance of the data from measuring dynamic friction coefficient (Table 1) showed that the main effects of variety, contact surface, grain moisture content and sliding velocity on the dynamic friction coefficient at the probability level of 1% were significant. Also, their interactions at the probability level of 1% on dynamic friction coefficient were significant with the exception of three and four interactions because the quality of grain varieties in different varieties and the quality of contact surface and the type of interaction of grains with contact surfaces were different. Similar results have been reported by other researchers (Chung et al., 1984; Gupta and Das, 1998; Kappuswamy and Wratten, 1970; Kaleemullah and Gunasekar, 2002).

Table 1 Results of variance analyze of data related to dynamic friction coefficient

Changes sources	Degree of freedom	Sum of squares	Mean of squares	F value
Variety (V)	4	0.103	0.026	35.3233**
Contact surface (CS)	3	1.006	0.335	459.7563**
Interactions (V×CS)	12	0.147	0.012	16.7452**
Moisture (MC)	2	1.445	0.722	990.5446**
Interactions (V×MC)	8	0.018	0.002	3.0727*
Interactions (MC×CS)	6	0.025	0.004	5.6762**
Interactions (MC×CS×V)	24	0.086	0.004	4.9043**
Sliding velocity (S)	2	0.250	0.125	171.6202**
Interactions (S×V)	8	0.056	0.007	9.6115**
Interactions (S×CS)	6	0.055	0.009	12.5682**
Interactions (S×CS×V)	24	0.025	0.001	1.4242^{ns}
Interactions (MC×S)	4	0.094	0.024	32.3202**
Interactions (V×MC×S)	16	0.015	0.001	1.3236^{ns}
Interactions (CS×V×MC×S)	12	0.014	0.001	1.5552^{ns}
Interactions (CS×V×MC×S)	48	0.015	0.001	0.4232^{ns}
Error	900	0.656	0.001	
Total	1079	4.01		

Note: **Significant effect at the probability level of 1%; * Significant effect at the probability level of 5%; ns not significant effect.

The obtained results from comparison of the mean main effects of the studied independent factors (Table 2), showed that dynamic friction coefficient means of *Azar*2 and *Sardari* varieties, *Sabalan* and Rasa, and *Rasad* and *Zagros* were not significant. The highest mean value (0.299) and the lowest mean value (0.273) of dynamic friction coefficient means were noticed in *Azar*2 and *Zagros* varieties, respectively. As result, at similar conditions, the conveyance power requirement of *Azar*2 variety was the highest.

Table 2 Comparison of the results of the mean main effects on dynamic friction coefficient

Testes varieties and their effects		Kind of contact surfaces and mean their effects		Sample moisture contact surfaces (w. b.) and mean their effects		Sliding velocity surfaces and main effects	
*Azar*2	0.299a	Black sheet	0.331a	18%	0.335a	15cm s^{-1}	0.298a
Sardari	0.295a	Aluminum sheet	0.293b	14%	0.273b	10cm s^{-1}	0.295a
Sabalan	0.284b	Mild sheet	0.272c	12%	0.249c	5cm s^{-1}	0.265b
Rasad	0.278bc	Galvanized sheet	0.248d				
Zaghros	0.273c						

Note: Similar letters indicate the significant difference (at the probability level 5%) of the mean main effects.

Also, the results showed that tested contact surfaces effects means were significantly (P<5%) different, as black and galvanized surface have been the most (0.331) and lowest (0.248) dynamic friction coefficient means. Consequently, among tested surfaces, the friction force and requirement power were minimized at conveyors which constructed from galvanized sheets. By increasing grain moisture content levels from 12% to 18% w. b., dynamic friction coefficient increased significantly from 0.249 to 0.335 because with increasing moisture content of grains, the adhesion force increased. These findings were confirmed by Gupta and Das (1998), Thampson and Ross (1983). By increasing speed level from 5 to 10 cm s^{-1}, the dynamic friction coefficient mean significantly increased while by increasing the sliding speed from 10 to 15 cm s^{-1}, it did not increase significantly. At higher moisture content, as wheat grains were sticky in nature, adhesive force played an important role in increasing the value of the dynamic friction coefficient. Similar results were founded by Kaleemullah and Gunasekar (2002), Chandrasekar and Viswanathan (1999), AskariAsli-Ardeh et al. (2010) at study of other agricultural crops grains. The comparison results of the mean interactions of varieties and contact surfaces material on dynamic friction coefficient (Figure 2) indicated that the highest (0.355) and the lowest (0.226) dynamic friction coefficient have been allocated to *Azar*2 and *Sabalan* varieties and black and galvanized steel surfaces, respectively. At test with all varieties, with change at contact surface, the dynamic friction means increased. The more tests, the variations were more significant.

The results of the interactions mean comparison of grain moisture content in variety (Figure 3) indicated that in tests with all varieties, by increasing grain moisture content from 12% to 18% w. b., dynamic friction coefficient significantly increased. The results were consistent with the results obtained by Thampson and Ross (1983) on the investigation of the effect of moisture on the dynamic friction coefficient of wheat. Among the varieties, the highest mean dynamic friction coefficient (0.352) was obtained in the test with *Azar*2 variety and the lowest mean dynamic friction coefficient (0.236) was obtained in the test with *Zagros* variety in the grain moisture content level 12% and 18% w. b., respectively.

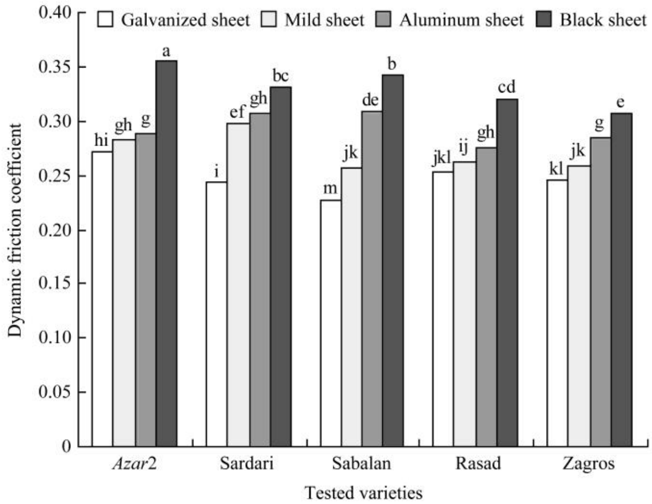

Figure 2 Effects of contact surface on the dynamic friction coefficient

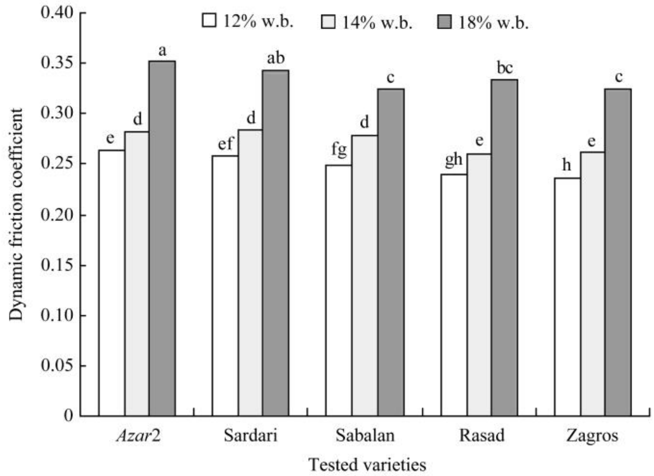

Figure 3 Effects of moisture content and the wheat variety on dynamic friction coefficient

The following equations show the linear relationship between the dynamic friction coefficient and the grain moisture content (M) in tests with the grain wheat varieties

for *Azar*2 variety $\mu_d = 0.0219MC - 0.00069$ R^2=0.89

for *Sardari* variety $\mu_d = 0.0215MC - 0.0053$ R^2=0.96

for *Sabalan* variety $\mu_d = 0.0192MC + 0.0153$ R^2=0.98

for *Rasad* variety $\mu_d = 0.0238MC - 0.055$ R^2=0.90

for *Zagros* variety $\mu_d = 0.0222MC - 0.0373$ R^2=0.95

The results of the mean moisture content interactions at the contact surface (Figure 4) showed that dynamic friction coefficient significantly increased on all three contact surfaces by increasing moisture content. The highest and the lowest mean dynamic friction coefficient obtained in black sheet (0.384) and galvanized sheet (0.213) were found at the moisture content of 18% and 12% w. b., respectively.

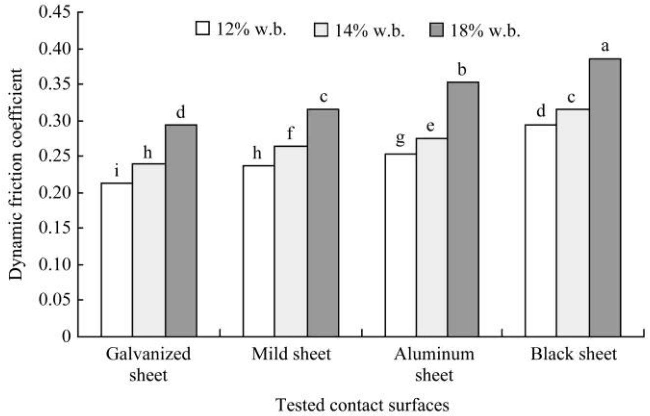

Figure 4 Effects of moisture content and contact surface

The mean comparison results of the interactions of moisture content and sliding velocity (Figure 5) showed that by increasing the moisture content of grains in three sliding speed levels (5, 10, 15 cm s^{-1}), the dynamic friction coefficient significantly increased. These results were supported by the results of Askari Asli-Ardeh et al., (2010) for paddy. The highest (0.364) and the lowest (0.240) mean dynamic friction coefficients were achieved at the speeds of 15 and 5 cm s^{-1} and moisture content levels of 18% and 12 % w. b., respectively.

The variation in the dynamic friction coefficient with the sample sliding speed (V) in tests with different moisture content different levels can be represented by following nonlinear equations:

for 12% w. b. $\mu_d = -0.0005V^2 + 0.0102V + 0.2013$ R^2=1

for 14% w. b. $\mu_d = -0.0004V^2 + 0.0103V + 0.228$ R^2=1

for 16% w. b. $\mu_d = -0.0005V^2 + 0.0157V + 0.233$ R^2=1

The mean comparison results of interactions of grain variety and sliding speed on dynamic friction coefficient are given in Figure 6. The results showed that in all varieties, by increasing sliding speed level from 5 to 10 cm s^{-1}, the friction coefficient significantly increased while by increasing sliding speed from 10 to 15 cm s^{-1}; the dynamic friction coefficient did not significantly increase with the exception of *Sabalan* variety. Among all varieties, the highest mean dynamic friction coefficient (0.321) was obtained in *Sardari* at the speed of 15 cm s^{-1}.

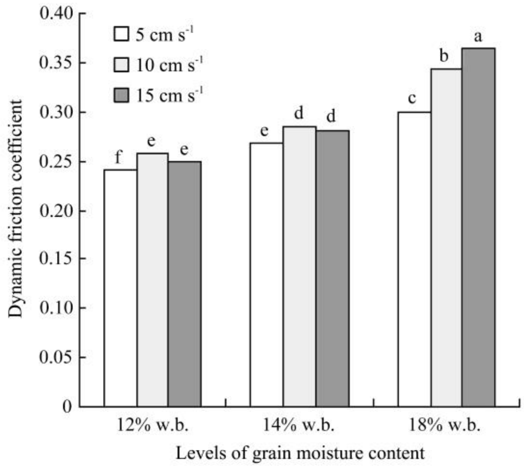

Figure 5 Effects of moisture content and sliding velocity on dynamic friction coefficient

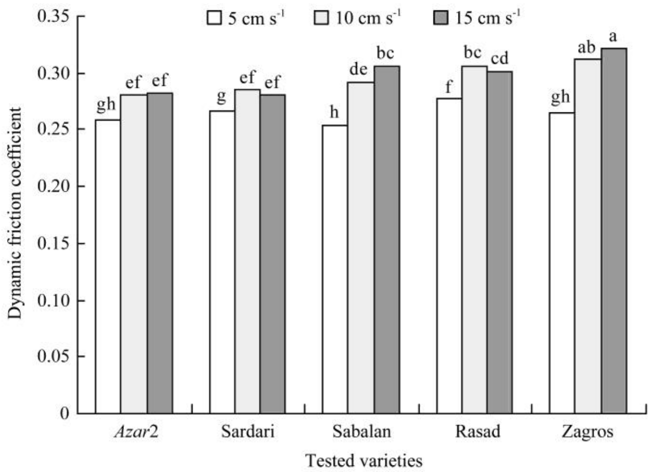

Figure 6 Effects of grain variety and sliding speed on dynamic friction coefficient

The results of mean comparison results of interactions of connect surfaces and sliding speed on dynamic friction coefficient (Figure 7) showed that in tests with galvanized and mild sheets, dynamic friction coefficient significantly increased by increasing sliding speed. At tests with Aluminum sheet, by increasing speed from 5 to 10 cm s^{-1}, the dynamic friction coefficient significantly increased, while by increasing speed from 10 to 15 cm s^{-1}, the dynamic friction coefficient significantly decreased. At tests with black sheet, by increasing speed from 5 to 15 cm s^{-1}, the dynamic friction coefficient significantly increased exception at tests with black sheet and variation of sliding speed from 10 to 15 cm s^{-1}. The mean comparison results of interactions of the four factors indicated that the highest effect mean (0.434) were achieved in *Azar*2 at moisture content level of 18 % w. b. with the black sheet and the sliding speed of 15 cm s^{-1}.

The variation in the dynamic friction coefficient with the sample sliding speed in tests with tested grain varieties can be represented by following nonlinear equations:

for *Azar*2 variety $\mu_d=-0.0007V^2+0.0161V+0.2145$ $R^2=1$

for *Sardari* variety $\mu_d=-0.0008V^2+0.0215V+0.177$ $R^2=1$

for *Sabalan* variety $\mu_d=-0.0005V^2+0.0146V+0.194$ $R^2=1$

for *Rasad* variety $\mu_d=-0.0004V^2+0.0101V+0.2275$ $R^2=1$

for *Zagros* variety $\mu_d=-0.0027V^2+0.0444V+0.1032$ $R^2=1$

4 Conclusions

In general, a significant difference was observed among the means of the dynamic friction coefficient of tested grain wheat varieties, the grain sample sliding speed and grain moisture content. Among the tested varieties, *Azar*2 and *Zagros* had the highest and the lowest dynamic friction coefficient, respectively. Among all tested contact surfaces, black and galvanized sheets had the highest and the lowest dynamic friction coefficients, respectively. By increasing the grain moisture content from 12% to 18% w. b. and the sample sliding speed from 5 to 15 cm s^{-1}, there were 35% and 12% increasing in the dynamic friction coefficient values of wheat grains, respectively. The highest effects mean (0.434) was achieved in *Azar*2 at moisture content level of 18% w. b. with the black sheet and the sliding speed of 15 cm s^{-1}. However, the equipments used to convey the grain wheat varieties under different conditions would have different capacity, required power and volumetric efficiency.

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