COEFFICIENT OF FRICTION OF POTATO *(Solanum tuberosum L.)* TUBERS IN DIFFERENT SURFACES*

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ABSTRACT

The static and dynamic coefficients of friction were determined for four industrial potato varieties produced in commercially in Turkey (Agria, Marabel, Marfona and Sante) against five different surfaces (galvanized sheet, court fabric, stainless steel, rubber and iron sheet). The peak static and average dynamic coefficient of friction parameters were considered as the dependent variables, and variety and frictional surfaces as the independent variable. The temperature recorded in the laboratory during the experiments was 21 ± 3 ^{0}C and moisture content of potato tubers was % 72.93-84.59 *w.b.* Experiment results were evaluated statistically. The static coefficients of friction values ranged from 0.478-0.820 for court fabric, from 0.326-0.507 for iron sheet, 0.143-0.469 for galvanized sheet, 0.220-0.397 for rubber, 0.210-0.470 for stainless steel. The dynamic coefficients of friction values ranged from 0.370-0.607 for court fabric, 0.354-0.480 for iron sheet, 0.182-0.420 for galvanized sheet, 0.210-0.409 for rubber, 0.186-0.397 for stainless steel. The analysis of variance showed that varieties and test surfaces on the static and dynamic coefficient of friction is significant (P<0.01). Among the structural surfaces, court fabric has the highest value of the average static and dynamic coefficient of friction and galvanized sheet has the lowest one.

Key words: Potato (*Solanum tuberosum L.*), Coefficient of Friction, Abrasion Surface

Patates (*Solanum tuberosum L.*)Yumrularının Farklı Yüzeylerdeki Sürtünme Katsayıları

ÖZET

Türkiye'de ticari olarak üretimi yapılan dört patates çeşidinin (Agria, Marabel, Marfona ve Sante) beş farklı yüzey üzerinde (galvanize sac, kort bezi, paslanmaz çelik, lastik ve sac) statik ve dinamik sürtünme katsayıları belirlenmiştir. Çalışmada statik ve dinamik sürütnme katsayıları bağımlı değişken, çeşit ve sürtünme yüzeyleri ise bağımsız değişken olarak alınmıştır. Test süresince laboratuar sıcaklığı yaklaşık 21 ± 3 ^{0}C olarak ölçülmüş, patates yumrularının nem düzeylerinin ise yaş baza göre % 72.93-84.59 aralığında olduğu tespit edilmiştir. Deney sonuçları istatistiksel olarak analiz edilmiştir. Statik sürtünme katsayısı değerleri kort bezi için 0.478-0.820, sac yüzey için 0.326-0.507, galvanize sac için 0.143-0.469, lastik yüzey için 0.220-0.397, paslanmaz çelik için ise 0.210-0.470 aralığında değişim göstermiştir. Dinamik sürtünme katsayısı değerleri ise kort bezi için 0.370-0.607, sac yüzey için 0.354-0.480, galvanize sac için 0.182-0.420, lastik yüzey için 0.210-0.409, paslanmaz çelik için 0.186-0.397 aralığında değişim göstermiştir. Yapılan varyans analizi sonuçlarına göre çeşit ve sürtünme yüzeyi bağımsız değişkenlerinin statik ve dinamik sürtünme katsayıları üzerinde istatistiksel olarak önemli etkileri olduğu görülmüştür (P<0.01). Sürtünme yüzeyleri içinde kort bezi en yüksek, galvanize sac ise en düşük statik ve dinamik sürtünme katsayısı değerlerini veren yüzeyler olmuştur.

Anahtar Kelimeler: Patates (*Solanum tuberosum L.*), Sürtünme Katsayısı, Sürtünme Yüzeyi

INTRODUCTION

Potato (*Solanum tuberosum* L.) is one of the world major agricultural crops and it is consumed daily by millions of people from diverse cultural backgrounds. Potatoes are grown in approximately 80 % of all countries and worldwide production stands in excess of 300 millions tones/year, a figure exceeded only by wheat, maize and rice (Duran et al., 2007). According to years of the 2009 FAO statistics, total potato production in Turkey is 4.39 million tones in 143 thousand ha (FAO, 2011).

Potato tubes are exposed to physical damage during harvest and postharvest processes and skin surface is susceptible to abrasion during these treatments. Knowledge of the abrasion resistance of potato is important information particularly during mechanical harvesting, handling and also in storage. The coefficient of friction is an important physical property in engineering design of equipment for harvesting and handling to minimize abrasion of products (Puchalski and Brusewitz, 1996).Also, the coefficients of friction are important parameters in the design of potato handling equipment and storage structures.

Most friction coefficient research conducted about granular material as pumkin seed (Joshi et al., 1993), lentil seed (Çarman, 1996), cumin seed (Singh

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and Goswami, 1996), sunflower seed and kernel (Gupta and Das, 1998). Also there are some research with larger particle size i.e. orange (Chen and Squire, 1971; Sabahoğlu et al., 2001; Topuz et al., 2005), orange and sweet lemon (Singh et al., 2004), watermelon (Puchalski and Brusewitz, 1996), apple (Puchalski and Brusewitz, 2001; Puchalski et al., 2002), grapefruit (İnce and Vursavuş, 2008) and potato (Argue, 1964; Mohsenin, 1965; Schaper and Yaeger, 1992).

The objective of this study was to measure the some physical properties of potato tubers and to determine the influence on peak static and average dynamic coefficient of friction (COF_S and COF_D) of potato of the following factors: type of surface and potato variety.

MATERIAL and METHOD

Potato tubers of Agria, Marabel, Marfona and Sante varieties for reproduction used in this study were obtained from Nevşehir Potato Research Institute, the production of the year 2010 (harvested on October-November season) grown around Nevşehir region in Turkey. The tubers were cleaned carefully from soils and damaged, immature or spoilt samples were removed. The moisture contents of potato were determined by using the standard hot air oven method at least 100-150 g samples and expressed in wet basis (Yurtlu et al., 2010).

To determine the average size, a sample of 100 potato tubes from each variety was randomly selected. The moisture content of potato was determined by using the standard hot air oven method (Sacilik, 2003). The tree main dimensions namely length (L), width (W) and thickness (T) of potato were determined by using a digital calliper having an accuracy of 0.01 mm. The geometric mean diameter, sphericity ($\varnothing$), surface area (S) and volume (V) were calculated according to Yurtlu et al. (2010). The volume of individual potato tube was calculated using the equation used by Vursavuş and Özgüven (2004). The angle of repose (θ) was obtained from method given by Yurtlu et al. (2010).

The friction coefficients of potato were measured by Lloyd Instrument Universal Testing Machines (Lloyd Instrument LRX Plus, Lloyd Instruments Ltd, An AMATEK Company). The device has tree main parts: moving head, driving unit and data acquisition system (load cell, note book and connections and NEXYGEN Plus software). The device was equipment with a load cell of 100 N and measurement accuracy of load cell was 0.5 % for the friction force measurement. Load cell was fixed to moving head. A special apparatus was positioned to the testing device for the friction test. This is an equal level supporting frame for the abrasion surfaces. A bottomless box (60x120x100 mm) that was filled with potato tubes was fixed to the load cell with steel cable and was pulled over a test surface (Figure 1).

There was approximately 10 mm clearance between the box frame and test surface during the tests. The mass of the potato tubes was measured for each observation and was used in all COF calculations. For each test, the travel distance of the Lloyd Material Testing Machine cross head was set at a distance of 120 mm. The test table height was adjusted so that the cable between the box and the pulley was always in a horizontal position. The horizontal pull (friction force) was measured by the Lloyd instrument and continually recorded. In this research friction test was conducted at 100 mm/min sliding speed and five abrasion surfaces (galvanized sheet, court fabric, stainless steel, rubber and iron sheet) were used. All surfaces were cleaned by compressed air and dry cloth before each test to prevent any effects of contamination from previous tests. The COF_S and COF_D values were calculated and evaluated according to İnce and Vursavuş (2008) methods. Figure 2 shows the output of the software as a sample of force-travel distance curve for friction coefficient tests of potato tubers. Ten replicates were run against all abrasive surfaces for each variety. Factorial experimental design on completely randomized model was utilized to obtain interaction term. When the interaction term was found as statistically significant, one way ANOVA analysis was performed on pooled data. Differences among means were determined with Duncan's multiple range tests. The studied parameters are summarized in Table 1. SPSS statistical program was used to determine the effect of dependent parameters on coefficient of frictions of potato tubes.

Figure 1. Friction test device

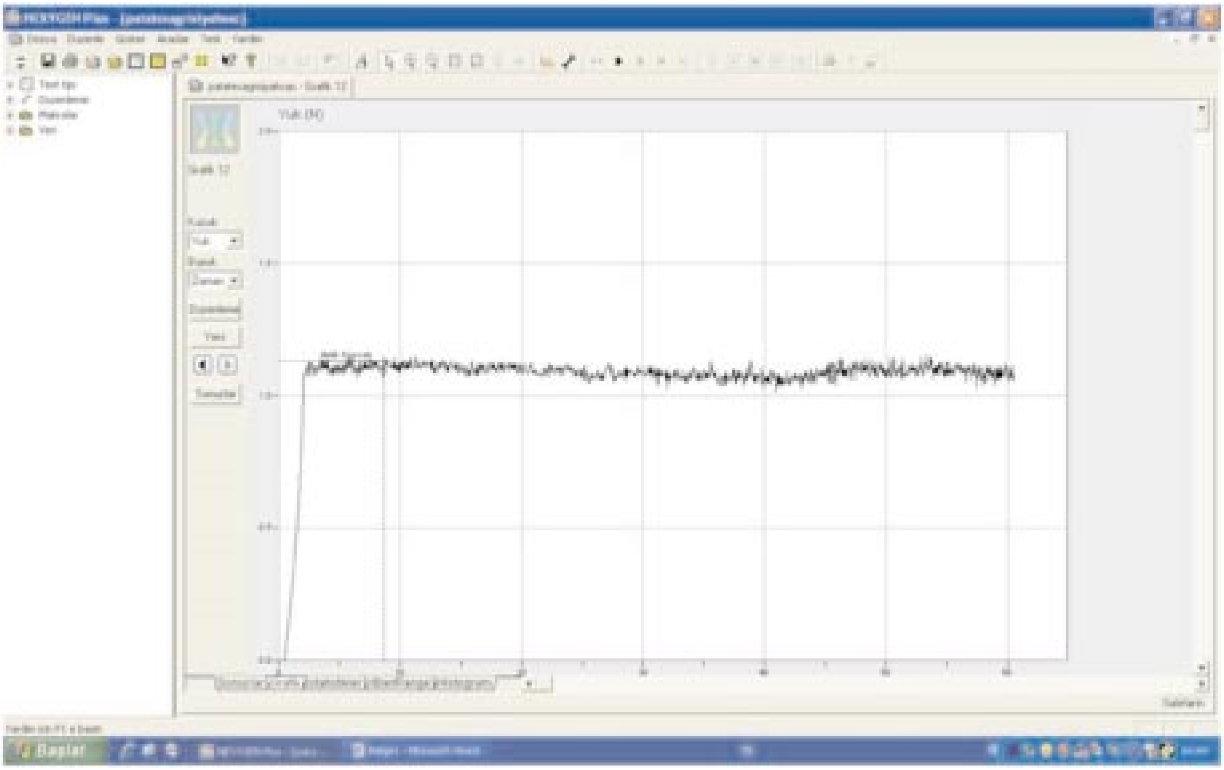

Figure 2. A sample of force-travel distance curve for friction coefficient tests of potato tubers

Table 1. Dependent and controlled variable parameters

Controlled Variable Parameters	
Abrasion surface	Galvanized sheet, Court fabric, Stainless steel, Rubber, Iron sheet
Variety	Agria, Marabel, Marfona, Sante
Dependent Variables	
Peak static coefficient of friction	COF_S
Average dynamic coefficient of friction	COF_D

RESULT and DISCUSSION

A summary of the physical dimensions, geometric mean diameter, sphericity, volume, mass, surface area, angle of repose and moisture content for the potato tubers varieties are shown in Table 2. The moisture content of potato tubes found between % 72.93 and 84.59 during the tests depends on the varieties. The maximum angle of repose (29.54^0) measured for Marfona potato variety. The minimum angle of repose (26.62^0) occurred for Sante variety. Schapper and Yaeger (1992) measured the average filling angle of repose for Irish potatoes between 30 and 35°. The researcher also advised that it can be estimated from the peak static coefficient of friction for potatoes on potatoes. The minimum and maximum values of both static and dynamic coefficients of friction for the five abrasion surfaces and four potato varieties are given in Table 3. The COF_S values ranged from 0.478-0.820 for court fabric, from 0.326-0.507 for iron sheet, 0.143-0.469 for galvanized sheet, 0.220-0.397 for rubber, 0.210-0.470 for stainless steel. The COF_D values ranged from 0.370-0.607 for court fabric, 0.354-0.480 for iron sheet, 0.182-0.420 for galvanized sheet, 0.210-0.409 for rubber, 0.186-0.397 for stainless steel. Court fabric and iron sheet which have the higher COF_D are materials with a high risk of damage, while the others especially rubber and stainless steel which have the lowest COF_D values have less risk of damage to potato.

As given in Table 4, the results of analysis of variance (ANOVA) showed that abrasion surface and variety, which were used as controlled variable parameters in the laboratory tests, significantly affected both the static and dynamic coefficient of friction. The effects of the main factors were considerably significant. Also, the interaction of two main factors was being significant.

Table 5 summarized all measurement parameters and some statistical values of experiment.

Table 2. Means and standard errors of physical properties of the potatoes varieties

Properties	*Varieties*			
	Agria	*Marabel*	*Marfona*	*Sante*
Moisture content (*w.b.*), %	84.59	72.93	77.35	74.51
Length, mm	72.00 ± 1.08	71.98 ± 1.16	71.10 ± 0.99	69.76 ± 1.09
Width, mm	59.66 ± 0.73	52.46 ± 0.65	58.34 ± 0.71	60.45 ± 0.61
Thickness, mm	48.49 ± 0.60	46.43 ± 0.50	51.89 ± 0.66	53.03 ± 0.58
Geometric mean diameter, mm	59.15 ± 0.60	55.84 ± 0.56	60.06 ± 0.53	60.61 ± 0.61
Sphericity, %	0.83 ± 0.01	0.78 ± 0.01	0.84 ± 0.01	0.87 ± 0.01
Volume, cm^3	110.4 ±3.49	92.8 ± 2.8	115.1 ± 3.14	118.7 ± 3.59
Mass, g	280.41 ± 2.80	277.43 ±3.48	301.06 ± 2.69	296 ± 4.09
Surface area, cm^2	110.6 ± 2.29	98.5 ± 1.9	113.9 ± 2.06	116.1 ± 2.33
Angle of repose, deg	29.47 ± 0.45	28.14 ± 2.92	29.54 ± 2.45	26.62 ± 1.02

Table 3. Minimum and maximum values of static and dynamic coefficient of friction for different potato varieties and surfaces

Variety		*Agria*		*Marabel*	
Surface	*Coefficient of Friction*	*Min.*	*Max.*	*Min.*	*Max.*
Galvanized sheet	COF_S	0.183	0.319	0.350	0.469
	COF_D	0.182	0.277	0.310	0.420
Court fabric	COF_S	0.539	0.799	0.572	0.820
	COF_D	0.471	0.537	0.340	0.607
Stainless steel	COF_S	0.365	0.470	0.283	0.354
	COF_D	0.340	0.397	0.294	0.343
Rubber	COF_S	0.220	0.369	0.341	0.397
	COF_D	0.210	0.313	0.308	0.341
Iron sheet	COF_S	0.366	0.459	0.326	0.507
	COF_D	0.373	0.450	0.396	0.440

Variety		*Marfona*		*Sante*	
Surface	*Coefficient of Friction*	*Min.*	*Max.*	*Min.*	*Max.*
Galvanized sheet	COF_S	0.143	0.401	0.264	0.405
	COF_D	0.253	0.308	0.251	0.306
Court fabric	COF_S	0.585	0.788	0.478	0.695
	COF_D	0.439	0.538	0.432	0.539
Stainless steel	COF_S	0.299	0.462	0.210	0.270
	COF_D	0.339	0.397	0.186	0.272
Rubber	COF_S	0.299	0.365	0.299	0.353
	COF_D	0.286	0.409	0.256	0.296
Iron sheet	COF_S	0.361	0.499	0.360	0.492
	COF_D	0.354	0.480	0.393	0.457

COF_S : Static coefficient of friction; COF_D : Dynamic coefficient of friction

Table 4. F-Values from ANOVA on the main effects and interaction

Source of Variation	*DF*	COF_S	COF_D
Abrasion surface, *AS*	4	344.515**	416.100**
Variety, *V*	3	13.151**	24.807**
AS x V	12	8.452**	12.907**
Error	180	-	-

DF : Degrees of freedom, COF_S : Static coefficient of friction, COF_D : Dynamic coefficient of friction

** Significant at the 0.01 level of significance

Table 5. Measurement parameters and some statistical values

Varieties	*Abrasion Surface*	*Static Coefficient of Friction*	*Dynamic Coeff. of Friction*
Agria	Galvanized sheet	0.269 ± 0.014	0.248 ± 0.011
	Court fabric	0.705 ± 0.025	0.501 ± 0.007
	Stainless steel	0.424 ± 0.009	0.373 ± 0.006
	Rubber	0.307 ± 0.013	0.276 ± 0.010
	Iron sheet	0.425 ± 0.008	0.363 ± 0.007
Marabel	Galvanized sheet	0.396 ± 0.015	0.336 ±0.010
	Court fabric	0.696 ± 0.022	0.529 ± 0.022
	Stainless steel	0.329 ± 0.007	0.316 ± 0.005
	Rubber	0.366 ± 0.005	0.318 ± 0.004
	Iron sheet	0.457 ± 0.016	0.420 ± 0.004
Marfona	Galvanized sheet	0.316 ±0.023	0.282 ± 0.005
	Court fabric	0.668 ±0.022	0.503 ± 0.009
	Stainless steel	0.394 ±0.017	0.375 ± 0.005
	Rubber	0.329 ±0.007	0.320 ± 0.010
	Iron sheet	0.420 ±0.015	0.421 ± 0.012
Sante	Galvanized sheet	0.328 ± 0.016	0.272 ± 0.005
	Court fabric	0.614 ± 0.023	0.480 ± 0.009
	Stainless steel	0.253 ±0.006	0.243 ± 0.007
	Rubber	0.320 ±0.005	0.279 ± 0.003
	Iron sheet	0.423 ±0.013	0.423 ± 0.008
Means			
Agria		0.425 ± 0.022^{b}	0.363 ± 0.013^{b}
Marabel		0.449 ± 0.019^{c}	0.384 ± 0.012^{c}
Marfona		0.426 ± 0.019^{b}	0.380 ± 0.011^{c}
Sante		0.388 ± 0.018^{a}	0.339 ± 0.013^{a}
	Galvanized sheet	0.327 ± 0.011^{a}	0.284 ± 0.006^{a}
	Court fabric	0.671 ± 0.012^{c}	0.503 ± 0.007^{e}
	Stainless steel	0.350 ± 0.012^{a}	0.327 ± 0.009^{c}
	Rubber	0.331 ± 0.005^{a}	0.298 ± 0.005^{b}
	Iron sheet	0.430 ± 0.007^{b}	0.420 ± 0.004^{d}
P values			
Variety		0.000	0.000
Abrasion Surface		0.000	0.000
Variety x Abr. Sur.		0.000	0.000

In each column, means with the same letters are not significantly different at 0.01 level of significance using Duncan's Multiple Range Test

According to the results, court fabric surface has the highest COF values in all potato varieties because of its rough surface. According to average values, after court fabric, the highest COF values were followed by iron sheet, stainless steel, rubber and galvanized sheet respectively.

Results of the Duncan's multiple range tests to determine significant differences among the means of the varieties and abrasive surfaces are given in Table 5. The ANOVA indicated that the variation of COF_S with varieties, surfaces and variety x surface interactions were significant ($P<0.01$). This trend is in agreement with the findings of earlier researcher (Schaper and Yaeger, 1992; Sabahoğlu et al., 2001; Singh et al., 2004; İnce and Vursavuş, 2008) who reported a significant effect of test surfaces on static and dynamic COF. The COF_S for court fabric was significantly higher than for any other surface. There is no significant difference among the COF_S values for stainless steel, rubber and galvanized sheet. The COF_S values for Marabel variety was significantly higher and for Sante variety was the lower than the other varieties. There is no significant difference between Agria and Marfona varieties. The highest COF_S (0.705) occurred with court fabric and Agria potato variety. The lowest (0.253) occurred with stainless steel surface and Sante variety. For the CFO_D, again, the ANOVA general significance results were the same as were found for the COF_S. The CFO_D was often similar trends in value to the COF_S on the test surfaces and varieties. The CFO_D of court fabric surface was significantly higher than for other surfaces. Also other surfaces were significantly different from each other for the CFO_D. The minimum CFO_D was found for galvanized sheet among the all test surfaces. The COF_D values for Marabel and Marfona varieties were significantly higher and for Sante variety was the lower than the other varieties. The highest COF_D (0.529) occurred with court fabric and Marabel potato variety. The lowest (0.243) occurred with stainless steel surface and Sante variety as the COF_S value.

CONCLUSION

1. On both COF, type of abrasion surface and varieties had a significant effect.
2. Among the all abrasion surface, court fabric caused the highest static and dynamic coefficients of friction. Galvanized sheet had the lowest static and dynamic coefficient of friction and cause less risk of damage for potato.
3. Potato varieties have significant effect on the COFs and COF_D for potatoes.
4. Type of surface has a significant effect on the COFs and COF_D for potatoes.
5. The mean COFs ranged from 0.705 for court fabric down to 0.253 for stainless steel.
6. The mean COF_D ranged from 0.529 for court fabric down to 0.243 for stainless steel.

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