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INFLUENCE OF MOISTURE ON EXTERNAL FRICTION COEFFICIENT AND BASIC PHYSICAL PROPERTIES OF ASTORIA VARIETY WHEAT GRAIN

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Abstract

This paper analyzed the effect of moisture content on selected physical properties of Astoria variety wheat grain using six levels of grain moisture content (14%, 16%, 18%, 20%, 22% and 24%). The following were determined for each level of moisture content: angle of repose, static angle of repose (SAR), bulk density and thousand kernel weight. The friction coefficients for four different construction materials (CEF) were also determined: acid-resistant steel, wear-resistant steel, plastic (PPLD) and rubber. It was found that an increasing moisture content in grains was accompanied by an increase in the thousand kernel weight, angle of repose, SAR, as well as the CEF against each of the surfaces used in the study. The highest value of the CEF was recorded for a rubber surface (0.782) and the smallest was for a polypropylene surface (0.443). The highest values of the angle of repose and the SAR were recorded for the grain with the highest moisture content: 37.15° and 39.44°, respectively. An increase in the moisture content in kernels reduced their bulk density from 79.870 $kg \cdot hl^{-1}$ (moisture content: 14%) to 68.783 $kg \cdot hl^{-1}$ (moisture content 24%).

Symbols

M – moisture content,
BD – bulk density [$kg \cdot hl^{-3}$],
TKW – thousand kernel weight [g],
μ – coefficient of externalfriction,
α – tilt angle [deg].

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Introduction

Understanding the interaction between biological material and the parts of a machine used for its processing lies at the foundation of the proper design of process installations (KUSIŃSKA 2001, MARKOWSKI et al. 2006). Cereals are of considerable importance in this regard, with wheat being one of the most commonly-grown crops. It accounts for about 29% of the total cereal production output, along with rice (28%) and maize (27%) (DENDY, DOBRASZCZYK 2001). Wheat is also the dominant cereal in Poland. The majority of global wheat production (75% ÷ 78%) is used in food production. Between 16% and 17% is used in industry and the rest is used as reproduction material (PSAROUDAKI 2007).

Physical properties depend on the species and variety, climate conditions, agrotechnical measures and moisture content (AL-MAHASNEHAND RABABAH 2007, MARKOWSKI et al. 2013, WARECHOWSKA et al. 2013). Moisture content in grain considerably affects its physical conditions (TABATABAEEFAR 2003, LASKOWSKI et al. 2005, KARIMI et al. 2009).

Understanding moisture content in grain is very important to engineers designing machines for grain harvesting and pre-processing, because there is sometimes a need to harvest grain with a high moisture content (DRESZER et al. 1998). The basic physical properties of grain are of particular importance, including bulk density, tapped density, angle of repose and static angle of repose (LEE, HERRMANN 1993, SPANDONIDIS, SPYROU 2013). Knowledge of these values is necessary to properly design such devices as: hoppers, intermediate containers and transport devices (KUSIŃSKA 2001, ZOU, BRUSEWITZ 2002). The external friction of grain mass is of particular importance. It is present in all processes to which grain is subjected. A high inconstancy in the value of the coefficient of the friction of bulk materials of plant origin often affects the operation that is being carried out (HORABIK, ŁUKASZUK 2000). Friction is an important factor affecting the course and outcome of processes of transport, storage, cleaning and sorting. Reliable information about its value is necessary in designing agricultural machines and processes (KRAM 2006). The range of friction coefficient values is very wide due to the diversity of materials of plant origin and their physical conditions. The external friction of one material may vary by several hundred percent (KRAM 2006).The aim of the study was to determine the relationships between the main physical properties and the coefficient of external friction of wheat grain and moisture content.

Materials and Methods

Astoria variety winter wheat grain (obtained from the AGRO-PLON Elżbieta Woycicka seed station in Ostróda, Poland) was used as the study material. The grain sample (approx. 18 kg) was cleaned before the measurements. The moisture content in the grain was determined by drying, in accordance with the Polish Standard PN-EN ISO 712:2009. The initial moisture content was 13.87%. The measurements were conducted at 6 levels of moisture content (*M*) (14%, 16%, 18%, 20%, 22% and 24%). In order to reach the desired moisture content, the grain was humidified in tightly-closed containers with a pre-calculated amount of distilled water. The moisture content was stabilized for 72 hours at 20±2°C and the grain was periodically stirred during the humidification process. Subsequently, the following physical properties of wheat grain were determined:

– static angle of repose (SAR) as per US 3940997 A (the tilting box method);

– angle of repose (AR) as per PN -65/Z-04005;

– bulk density as per PN 73/R-74007;

– thousand kernel weight (TKW) – with the use of an electronic grain counter (LN S 50A, UNITRA CEMI) and a WPE 120 Radwag (PN68/R-74017) electronic scale;

– coefficient of external friction (CEF) – a device with a tilting plate covered with a material of a friction pair (HORABIK et al. 2002).

The grain external friction was determined using four different construction materials, frequently applied in the construction of transporters and containers. These included:

– acid-resistant steel (1.4404);

– wear-resistant steel (1.0562);

– plastic (PPLD);

– rubber – the transport surface of a conveyor belt (a commercial product).

A knob was used to steadily increase the inclination angle of the plate, whose surface was made of the material of a friction pair. When the grain sample started to slide, the angle was read out from the scale of the device. The coefficient of friction was calculated using the formula (SHARMA et al. 2011):

$$\mu = \mathrm{tg}(\alpha) \qquad (1)$$

The results were then analyzed statistically. The basic statistical parameters were determined and an analysis of variance was conducted in order to determine how they depend on the moisture content in the material. The statistical calculations were performed with STATISTICA® for Windows v. 10 (StatSoft Inc.). Hypotheses were tested at the level of significance of $p = 0.05$.

Results and Discussion

Table 1 shows the results of measurements of the thousand kernel weight (TKW) and bulk density of Astoria variety wheat grain. The TKW with a moisture content of 14% was 49.69 g and it increased with increasing moisture content. The same tendency was observed by KUSIŃSKA et al. (2010). The TKWat the highest moisture content (24%) was 54.55 g. The TKW at a moisture content between 14–18% did not differ significantly. A similar relationship was observed for moisture content between 20–24%.

Table 1

Thousand kernel weight and bulk density of Astoria wheat grain at different moisture contents

M [%]	TKW [g]				BD [kg · hl^{-1}]			
	$\bar{x}$	min.	max	S	$\bar{x}$	min.	max	S
14*	49.699^{a}	48.333	50.386	0.778	79.870^{a}	79.724	80.057	0.100
16*	49.924^{a}	49.157	50.922	0.653	77.027^{b}	76.810	77.355	0.196
18*	50.957^{ac}	49.251	52.223	1.126	75.322^{c}	74.926	75.584	0.205
20*	52.810^{bc}	50.147	55.980	2.200	74.024^{d}	73.335	75.171	0.440
22*	53.895^{b}	53.092	55.636	1.015	70.938^{e}	70.438	71.391	0.302
24*	54.554^{b}	53.389	57.229	1.549	68.783^{f}	68.265	69.500	0.371

$\bar{x}$ – average value, S – standard deviation;
* averages marked with the same letters in a column do not differ statistically at p = 0.05 (homogenous group)

The measurement results for grain bulk density showed that a 2% change in the moisture content significantly changes density (Tab. 1). The highest bulk density was measured for grain with a moisture content of 14% (79.870 kg · hl^{-1}). Grain humidification steadily decreased its bulk density. The results obtained in the measurements corroborate the findings of TABATABAEEFAR (2003), who found an increase in the moisture content in grain reduced its bulk density.

KOBUS et al. (2010) examined the physical properties of triticale grain and found that the AR and SAR increased with increasing moisture content. The current study found similar relationships – the largest AR and SAR were observed for material with the highest moisture content (Tab. 2). ZOU and BRUSEWITZ (2002) showed that SAR is even lower than AR. In this study, we found that the above relationship occurs when the grain has a moisture content of less than 22%. At the highest grain moisture content (22–24%), the SAR values were lower than AR. This may indicate a decisive change physical mechanism of friction. As with bulk density, a 2% change in moisture content caused a statistically significant change in the SAR across the entire range of moisture content values under study. The AR changed significantly across nearly the entire moisture content range under study. Only at the highest grain moisture content (22–24%) did the AR change slightly (while the general tendency was maintained) and its values formed a homogeneous group.

Table 2
The angle of repose and the static angle of repose for Astoria wheat grain with different moisture contents

M [%]	Static angle of repose [°]				Angle of repose [°]			
	$\bar{x}$	min.	max	*S*	$\bar{x}$	min.	max	*S*
14	28.2[a]	27.8	28.5	0.238	30.8[b]	30.5	31.6	0.392
16	29.8[b]	29.2	30.6	0.514	31.8[c]	31.2	32.4	0.335
18	30.6[c]	30.3	30.9	0.179	34.1[d]	32.8	34.6	0.584
20	32.6[d]	32.1	33.3	0.314	35.1[e]	34.1	35.5	0.563
22	38.0[e]	37.2	38.8	0.525	36.9[a]	36.5	37.6	0.477
24	39.4[f]	38.7	40.0	0.488	37.2[a]	36.5	37.6	0.411

$\bar{x}$ – average value, *S* – standard deviation;
* averages marked with the same letters in a column do not differ statistically at $p = 0.05$ (homogenous group)

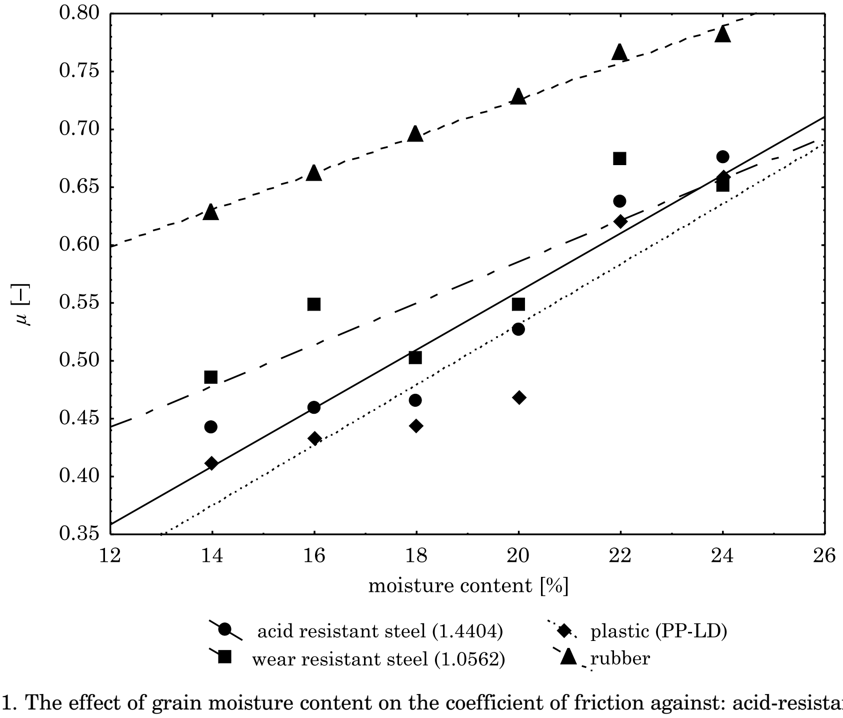

Fig. 1. The effect of grain moisture content on the coefficient of friction against: acid-resistant steel (1.4404), wear-resistant steel (1.0562), plastic (PPLD) and rubber

Kram (2006) found that the CEF of grain against different materials changed along with different grain moisture contents. This relationship was confirmed for each friction pair under study. The weakest friction interactions occurred between grains of Astoria wheat and a PPLD board (Fig. 1). Slightly stronger friction was present between the wheat grains and a stainless steel plate (1.4404).

As with the other friction pairs, the CEF of grain against a sheet of wear-resistant steel (1.0562) increased with increasing moisture content in grain. However, another variability was observed, which could not be explained on the basis of this experiment. The highest CEF was observed between grain and rubber, which is the standard working surface in belt conveyors.

The study also found that the CEF of Astoria wheat grains against each of the surfaces under study increased with increasing moisture content. The changes in the CEF values between grain and rubber (Fig. 1) were smaller than in the other friction pairs. According to the literature data, a change in the grain moisture content does not greatly affect the CEF between grain and a wooden surface (Kram 2006). The effect of changing moisture content on the CEF between grain and steel sheets and a polypropylene surface was similar (and was greater than for rubber). The results of a regression analysis for each of the physical features are shown in Figs. 2–5.

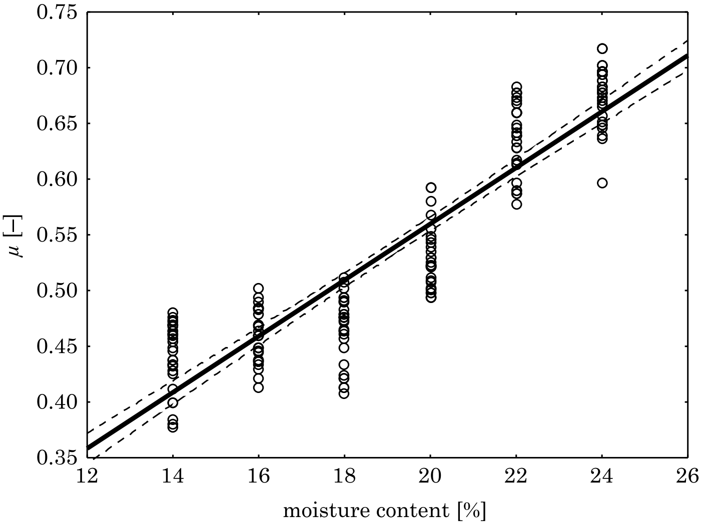

Fig. 2. The effect of grain moisture content on the friction of grain against an acid-resistant steel surface (1.4404)

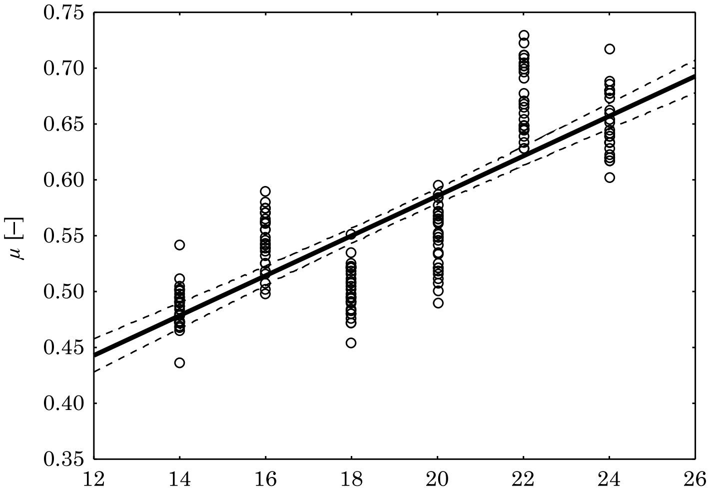

Fig. 3. The effect of grain moisture content on the friction of grain against awe ar-resistant steel surface (1.0562)

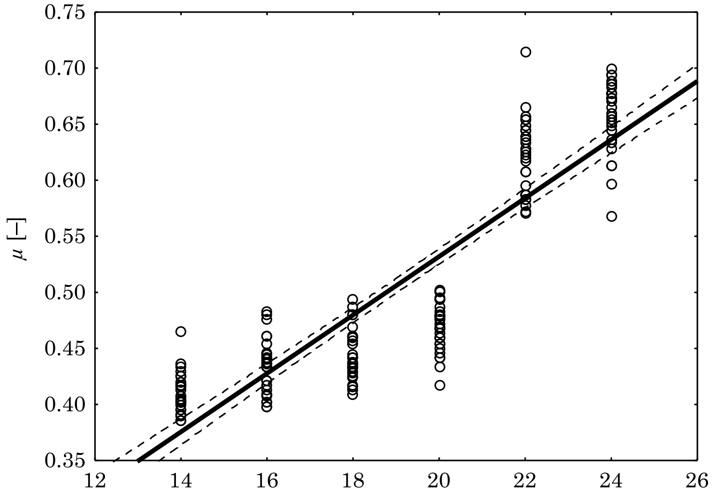

Fig. 4. The effect of grain moisture content on the friction of grain against a plastic surface (PPLD)

The equations describing the relationship between the CEF Astoria variety wheat grains and other surfaces are presented in Table 3. It also contains the correlation coefficients for each of the equations. The linear correlation coefficient between the grain moisture content and the CEF was high for each of the friction pairs under study. Its values were above 0.800, with a level of significance of p<0.0503.

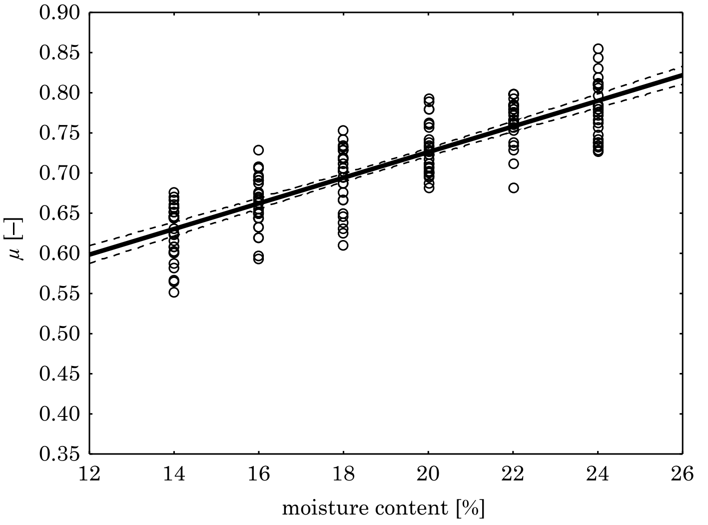

Fig. 5. The effect of grain moisture content on the friction of grain against a rubber surface

Table 3
The relationship between coefficient of friction of Astoria variety wheat grain against construction materials and moisture content

Material of the friction pair	Regression equation	Correlation coefficient for the adopted equation of regression
PPLD	$\mu = 0.011 + 0.026 \cdot \mathrm{M}$	$r = 0.893$
Steel 1.0562	$\mu = 0.229 + 0.018 \cdot \mathrm{M}$	$r = 0.811$
Steel 1.4404	$\mu = 0.056 + 0.025 \cdot \mathrm{M}$	$r = 0.905$
Rubber	$\mu = 0.407 + 0.016 \cdot \mathrm{M}$	$r = 0.855$

Coefficients of correlation statistically significant at $p < 0.0503$

The regression equation coefficients indicate that grain moisture affects the CEF of PPLD the most – over 95% of the value of the coefficient is associated with the moisture content (Fig. 1 and Tab. 3). The effect of grain moisture is two times greater than if in a pair of friction is molded plastic (KARIMI et al. 2009). The value of the intercept in the reported studies is 3 times smaller than in the case of pressed plastic obtained by KARIMI et al. (2009).

The grain moisture content affects the CEF against a rubber surface to the least extent (Fig. 5). In this case, the constant (0.407) which is part of the regression function, accounts for over 50% of the value (Tab. 3). Among the studied friction pairs, an increase in grain moisture had the least impact on CEF for wheat-rubber.

This is an advantage when considering that rubber is used as a standard working surface for conveyor belts. A slightly different friction correlation function for the friction of different wheat varieties of grain against a rubber surface was obtained by KRAM (2006). Compared to the plywood friction coefficient (KARIMI et al. 2009), rubber improved the friction pair for wheat grains. Moreover, CEF with plywood, when compared to rubber, was less dependent on grain moisture changes.

If steel is used as the friction surface, a change in moisture content from 14% to 24% increases the CEF by 37% for 1.0562 steel (Fig. 3) and 62% for 1.4404 acid-resistant steel (Fig. 2). For 1.4404 steel, the change in grain moisture had a 30% greater effect than galvanized steel friction (KARIMI et al. 2009). The value of the intercept in the correlational equation was three times smaller than that obtained for galvanized steel. The effect of changes in grain moisture on the coefficient of friction against 1.0562 steel is the same as in the case of galvanized steel (KARIMI et al. 2009) but the intercept values are greater than 0.05.

Conclusions

The coefficients of friction against rubber are significantly higher than those of grain against steel sheets or polypropylene, regardless of grain moisture content and they change the least with changing moisture content. The CEF of Astoria variety winter wheat increases in a linear manner with increasing grain moisture content. The thousand kernel weight, the angle of repose and the static angle of repose increase with an increasing moisture content in Astoria wheat grain. An increase in the moisture content in Astoria variety winter wheat results in a decrease in its bulk density.

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