Relationship between the Physical Properties of Maize Kernel and Metabolizable Energy for Pigs

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Summary

Recent research indicated that the physical properties of maize kernels may be used to evaluate its nutritional value. Therefore, the main objective was to determine the relationships between kernel physical properties and metabolizable energy (ME) for pigs in commercial maize hybrids widely grown in Croatia. Field experiment was conducted in Baranja over two growing seasons with 11 maize hybrids (six domestic hybrids from Bc Institute and five introduced Pioneer hybrids). Investigated hybrids belonged to various maturity groups (FAO 200-600). Growing season significantly affected kernel thickness, kernel length, test weight and ME for pigs, despite similar average 1000-kernel weight in both years of field research. Hybrids differed significantly in kernel length, kernel width, kernel thickness, test weight and 1000-kernel weight as well as in ME. The shortest-season hybrid Bc282 had the smallest 1000-kernel weight (on average 314 g), but the largest test weight (on average 79.8 kg/hl) and high ME (on average 16.70 MJ/kg). The smallest test weight and ME was found for hybrid PR36K67 (FAO 490) which had the highest kernel length (13.4 mm on average) and 1000-kernel weight (438g on average), and consequently, low kernel sphericity. Test weight weakly correlated with kernel thickness and kernel sphericity, while it positively correlated with ME. The highest ME had hybrids Bc 572, Bc 462 and PR34B23, while five hybrids had slightly lower values. Of all kernel physical properties, the test weight appears to be most reliable indicator for assessing ME for pigs in the kernels of commercial maize hybrids.

Key words

maize, hybrid metabolizable energy, test weight, 1000 kernel weight, kernel size

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Introduction

Maize is the most widely used energy feed in livestock production. Maize kernel has consistent composition and energy content, and therefore, animal nutritionists rarely evaluate ME (Summers, 2001). However, recent findings (Cantarelli et al., 2007; Moore et al., 2008; Lasek et al., 2012) have indicated that energy value of maize kernel may considerably vary among hybrids. Conventional methods for determining ME are rarely conducted because they are expensive, time-consuming and occasionally animal nutrition experiments are also needed. Therefore, estimates of ME based on the readily measurable properties of maize kernels are interesting for farmers and animal feeders (Dorsey-Redding et al., 1991).

Test weight is commonly used to assess the quality of maize kernels. It provides useful information for transactions, trade and storage because it shows how much volume is occupied by a given amount of maize kernel (Reed, 2006). Watson (2003) stated that the test weight of number one grade maize in the United States should be a minimum of 72.08 kg/hl. Test weight indicates the ripeness (Thornton et al., 1969) and hardness (Henry and Kettlewell, 1996) of maize kernel. Several researchers found no relationship between the test weight and ME for poultry (Muztar and Slinger, 1981; Lilburn and Dale, 1989; Leeson et al., 1993) or ME for pigs (Patterson et al., 1993; Johnson, 1995). In contrast, other studies (Leeson and Summers, 1976; Sunde and Holm, 1977; Baidoo et al., 1991) reported a trend toward smaller ME for poultry for maize kernels with low test weights. The negative relationship between maize kernels with a test weight lower than 62.5 kg/ha and ME for poultry was determined for 45 maize hybrids in an extensive research undertaken by Dale (1994). In comparison to favourable growing season, Grbeša (1990) and Baidoo et al. (1991) found significantly smaller test weights for maize crop grown under unfavourable weather conditions.

Differences in shape and size of maize kernels are mainly due to genetic background but distribution of kernels on ear could be also influenced by growing season (Nafziger, 2003). Shorter and thicker kernels are more vitreous than longer and thinner ones (Kirleis and Stroshine, 1990). Consequently, small and round vitreous kernels are more nutritious for some categories of domestic animals (Szaniel et al., 1984; Collins et al., 2001). High-spherical kernels of dent maize are more similar to semi-hard kernels of semi-flint maize than the less-spherical kernels (Pomeranz et al., 1985).

The aim of this research was to determine the relationships between the physical traits of maize kernels and ME for pigs for commercial maize hybrids in Croatia.

Materials and methods

Eleven maize hybrids were grown over two growing seasons (2007 and 2008) in a field experiment conducted on chernozem soil at Kneževo, northern Baranja. Six hybrids were originated from Bc Institute, Zagreb and five hybrids from the Pioneer seed company. Hybrids from Bc Institut were Bc282 (FAO 280), Bc354 (FAO 360), Bc418B (FAO 460), PAJDAŠ (FAO 490), Bc462B (FAO 460), and Bc572 (FAO 500). The introduced Pioneer hybrids were PR38A24 (FAO 380), PR36P85 (FAO 450), PR36B08 (FAO 480), PR36K67 (FAO 490) and PR34B23 (FAO 600). Tested hybrids were selected on the basis of two criteria. The first criterion was the belonging to various maturity groups, and the second that the tested hybrids are widespread in production, which makes this research applicable for extension purposes.

Field experiments were conducted under intensive production system for maize crop (Svečnjak et al., 2004). In both years of research, a single factorial experiment with 11 hybrids with three replications was established. Hybrids were sown at the recommended plant densities within the optimum sowing date (before 5th May). At sowing, plots consisted of eight rows that were 70 cm apart and 100 m in length. Following physiological maturity, ear samples were taken manually at five places in the four central rows. A total of 100 ears were hand-harvested and collected from each plot.

Ears were stored for a period of one month at the room temperature. Maize kernels were hand-shelled, mixed and then a sample was taken for physical and chemical analysis. The test weight was determined by standard Schopper Chondrometer methodology after the kernels were sieved to remove foreign material and broken kernels. The 1000-kernel weight was determined by counting 200 kernels and expressed on 14 % moisture content.

Kernel dimensions were determined using digital caliper on 50 whole kernels. Kernel length (a) was determined by measuring kernel from the base to the top. Kernel width (b) was measured so that the kernel was laid on a smooth surface and measured from one side to the other side of the kernel. Kernel thickness (c) represents the distance between the abdominal and rear side of kernel. Kernel sphericity (S) was calculated based on the formula (Mohsenin, 1970):

$$S = \frac{\sqrt[3]{abc}}{a}$$

The sphericity range from 0 to 1, values closer to 1 indicate more spherical kernel whereas values closer to 0 indicate smaller sphericity.

The ME content for pigs was calculated from the chemical composition according to the following equation (Noblet and Perez, 1993):

$$ME\ (MJ/kg) = [(4.194 - 9.2 \times Ash + 1.0 \times CP + 4.1 \times CF - 3.5 \times NDF) \times 4.184]/1000$$

Samples of maize kernels were analysed using standard methods (AOAC, 2002) for dry matter (DM; 934.01), crude protein (CP; 976.06), crude fat (CF; method 954.02), and ash (942.05). Neutral detergent fibre (NDF) was determined according to Mertens (2002) with the addition of thermo stable alpha amylase.

Statistical analysis of the data was performed by analysis of variance using the MIXED MODEL PROCEDURE (SAS Inst., 1997). Growing season and hybrids were considered as a fixed effect, whereas the repetitions were a random effect. Mean separation was calculated using the LSD values if the F-test was significant at P=0.05. Direct relationships among kernel physical properties and ME for pigs were analysed with simple Pearson correlation coefficients.

Results and discussion

Growing season significantly affected kernel thickness (Table 1). In 2008 kernel thickness averaged 5.06 mm while it averaged 4.70 mm in the previous (2007) growing season. Tested hybrids significantly (*P*=0.01) differed in kernel thickness. The thinnest kernel (an average of 4.37 mm) had hybrid PR34B23 whereas the hybrid PR38A24 had the thickest kernel (5.84 mm on average). In our research kernel thickness was similar to the range of 4.63 ± 0.85 mm reported by Soliman and Maksoud (2007).

A significant year × hybrid interaction (Table 1) indicated that tested hybrids differed for kernel thickness over two growing seasons. Most hybrids had thicker kernels in 2008 (Fig. 1). Only hybrids Bc282 and PR38A24 had the opposite pattern of response resulting in thicker kernels in 2007 when compared to 2008.

In contrast to the results for kernel thickness, growing season did not significantly affect kernel width (Table 1). However, tested hybrids varied significantly (*P*=0.01) in kernel width. The widest kernels in our research had hybrid PAJDAŠ (on average 8.96 mm). The narrowest kernels (7.40 mm on average) were detected for hybrid PR34B23 (Table 2). An absence of hybrid × year interaction (Table 1) indicated that tested hybrids responded similarly for kernel width in both growing seasons.

Maize kernel length in 2007 averaged 12.56 mm, while in the growing season of 2008 average kernel length was significantly smaller (12.24 mm on average). Kernel length was also significantly affected by hybrid (Table 1). The longest kernels (13.41 mm on average) were determined for hybrid PR36K67, whereas the shortest kernels (11.75 mm on average) had hybrid Bc462B. A significant (*P*=0.01) year × hybrid interaction was found because kernel lengths of tested hybrids differed across two growing seasons. This is in concordance with the results of Sito (1994) who also found that growing season may affect the length, width and thickness of maize kernels. In our research, most hybrids had longer kernels in the growing season of 2007 (Fig. 2). Only hybrids PR36K67 and PR38A24 showed an opposite pattern of response because they had higher values in the growing season of 2008. Kernel dimensions in our study are in agreement with the thickness, width and length of maize kernels given by Watson (2003) and Miao et al. (2006).

Average 1000-kernel weight was not significantly affected by growing season (Table 1). These results are consistent with other authors (Tollenar, 1992) who pointed out that this is the most consistent yield component due to relatively small variations in various environments. The largest 1000-kernel weight (438 g on average) was produced by hybrid PR36K67, while the

Table 1. Combined analysis of variance for the kernel physical properties and metabolisable energy (ME) for pigs in commercial maize hybrids.

Source of variation	Kernel thickness	Kernel width	Kernel length	1000-kernel weight	Test weight	Kernel sphericity	ME
Year (Y)	*	NS	**	NS	**	*	**
Error (a)	-	-	-	-	-	-	-
Hybrid (H)	**	**	**	**	**	**	*
Y × H	*	NS	**	**	**	**	NS
Error (b)	-	-	-	-	-	-	-

**, * Significant *F*-test *P*= 0.01 and *P*= 0.05, respectively; NS – Non-significant *F*-test.

Table 1. Combined analysis of variance for the kernel physical properties and metabolisable energy (ME) for pigs in commercial maize hybrids.

	Growing season	Kernel thickness (mm)	Kernel width (mm)	Kernel length (g)	1000 kernel weight (g)
	2007	4.7	8.16	12.56**	366NS
	2008	5.06*	8.17NS	12.24	365
Hybrid	Maturity group				
Bc282	FAO 280	4.49	8.25	12.00	314
Bc354	FAO 360	4.68	8.05	11.99	342
PR36A24	FAO 380	5.84	8.35	11.80	377
PR36P85	FAO 450	4.70	7.62	12.44	348
Bc418B	FAO 460	4.50	8.30	12.32	363
Bc462B	FAO 460	4.79	8.38	11.75	363
PR36B08	FAO 480	5.09	8.43	13.00	380
PAJDAŠ	FAO 490	5.26	8.96	12.53	399
PR36K67	FAO 490	5.04	8.20	13.41	438
Bc572	FAO 500	4.93	7.89	11.98	374
PR34B23	FAO 600	4.37	7.40	13.17	323
LSD (0.05)		0.55	0.42	0.39	9.2

**, * - Significant *F*-test at *P*= 0.01 and *P*= 0.05, respectively; NS – Non-significant *F*–test at *P*=0.05.

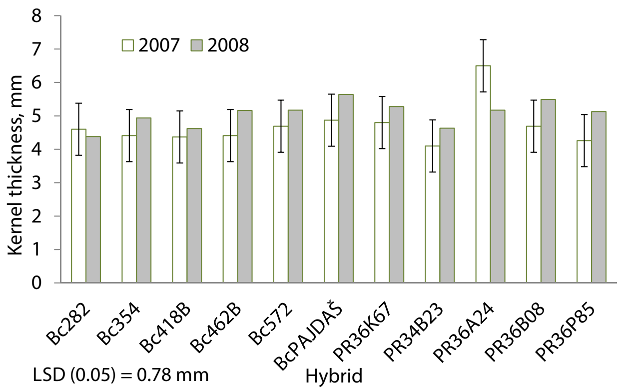

Figure 1. Effect of growing season on kernel thickness of maize hybrids. Kneževo, 2007 and 2008.

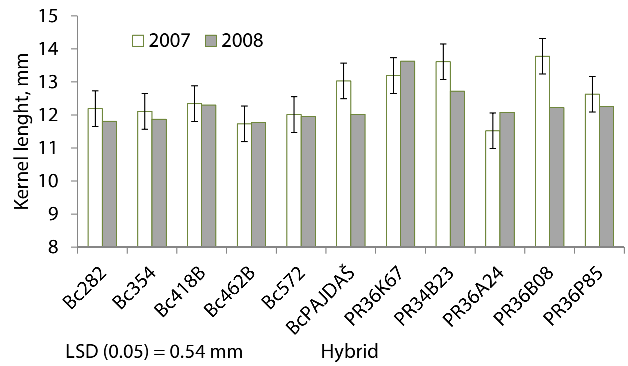

Figure 2. Effect of growing season on kernel length of maize hybrids. Kneževo, 2007 and 2008.

smallest 1000-kernel weight (314 g on average) was found for hybrid Bc282 (Table 2). Analysis of variance showed that significant differences existed between the hybrids of different FAO maturity groups for the 1000-kernel weight (Table 1). An average 1000 kernel weight for hybrid PR36K67 of FAO 490 maturity group was by 28% greater than average 1000-kernel weight for hybrid Bc282 from the FAO 280 maturity group. Svečnjak et al. (2004) reported that hybrids from the FAO 400 maturity group produced an average 1000-kernel weight of 342 g, which was by 8.6% larger than the average 1000-kernel weight of hybrids from the FAO 300 maturity group. In their study, the 1000 kernel weight of hybrids from the FAO 500 group averaged 335 g. Significant hybrid × year interaction (Table 1) indicated that hybrids differed in their response for 1000-kernel weight during two growing seasons. Most of hybrids had a higher 1000-kernel weight in the growing season of 2007 (Fig. 3). Only hybrids Bc462B, Bc572, PR36B08 and PR36P85 showed an opposite pattern of response.

Average test weights differed significantly across two growing seasons and among investigated hybrids (Table 1). In 2008, an average test weight of 79.1 kg/hl (Table 3) was significantly higher than the average of 76.5 kg/hl in the previous (2007) growing season. Grbeša (1990) also found a significant variation in test weights across different growing seasons. The average test weight values in our study are similar to those reported by Nielsen et al. (2002) and Miao et al. (2006) for dent hybrids as well as to findings of Grbeša (2007) for hybrids from the Bc Institute. Peplinski et al. (1992) found the test weight of commercial dent hybrids averaged 73.2 to 76.2 kg/hl. In our study, most hybrids in both years produced test weight higher than 72.7 kg/hl, which is a standard for the number 1 grade maize in the United States. The highest average test weight was found for hybrid Bc282 (79.8 kg/hl) and the smallest for hybrid PR36K67 (74.8 kg/hl). The latter hybrid is characterised by the longest kernel (13.4 mm on average) and the heaviest 1000-kernel weight (Table 2). This hybrid also had high kernel thickness and kernel width (Table 2). Test

Table 3. Test weight, kernel sphericity and metabolizable energy (ME) for pigs of maize hybrids belonging to the FAO 200-600 maturity groups. Kneževo, 2007 and 2008.

	Growing season	Test weight (kg/hl)	Kernel sphericity (kg/hl)	ME for pigs (MJ/kg)
	2007	76.5	0.6244	16.37
	2008	79.1**	0.6509**	16.97**
Hybrid	Maturity groups			
Bc282	FAO 280	79.8	0.6357	16.70
Bc354	FAO 360	78.2	0.6392	16.75
PR36A24	FAO 380	76.8	0.7038	16.50
PR36P85	FAO 450	78.6	0.6135	16.59
Bc418B	FAO 460	75.4	0.6260	16.49
Bc462B	FAO 460	78.6	0.6615	16.85
PR36B08	FAO 480	77.3	0.6348	16.62
PAJDAŠ	FAO 490	78.7	0.6693	16.76
PR36K67	FAO 490	74.8	0.6119	16.44
Bc572	FAO 500	79.5	0.6464	16.86
PR34B23	FAO 600	77.8	0.5719	16.83
	LSD (0.05)	0.6	0.0071	0.29

** - Significant F-test at P=0.01

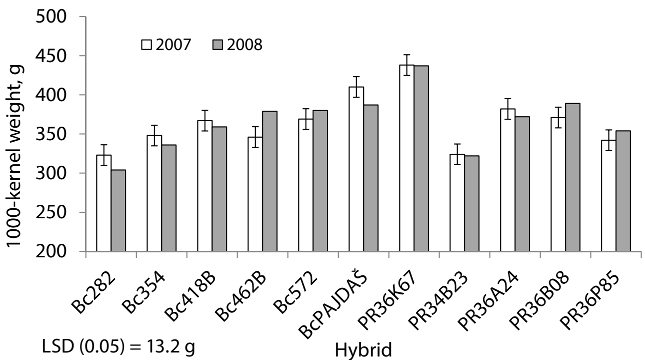

Figure 3. Effect of growing season on 1000-kernel weight of maize hybrids. Kneževo, 2007 and 2008.

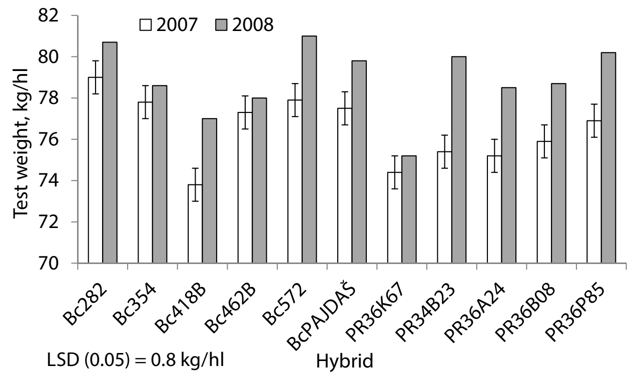

Figure 4. Effect of growing season on the test weight of maize hybrids. Kneževo, 2007 and 2008..

weight negatively correlated with kernel length (r=-0.46*), which could partly explain low test weight for hybrid PR36K67 (Table 4). When compared with hybrid PR36K67, hybrid PAJDAŠ had significantly shorter kernel (an average of 12.5 mm) but the greatest kernel width of all hybrids (an average of 8.96 mm) and high kernel thickness (an average of 5.26 mm). Matin et al. (2007) reported significant differences in kernel sphericity between the hybrids originating from seed companies Bc Institute (Bc 4982, Bc 462, Bc Jumbo) and Pioneer ('Florencia' and 'Stefania'). Authors found that the largest kernel sphericity had hybrid Bc 462, while the smallest kernel sphericity had hybrid Florencia. Pomeranz et al. (1985) reported that kernels with higher sphericity are more flint-type when compared to kernels with small sphericity. High kernel thickness and kernel width brought about a high 1000-kernel weight for hybrid PAJDAŠ (Table 4). Interestingly, this hybrid also had a relatively high test weight of 78.7 kg/hl, which most likely resulted from the largest kernel sphericity (Table 2). Pomeranz et al. (1985) showed that flat (less spherical) kernels had 1.93 kg/hl lower test weight than round (more-spherical) kernels. In our study, a negative relationship between kernel sphericity and kernel length existed (Table 4), and as expected, a positive correlation between kernel sphericity, kernel thickness and kernel width.

A significant year × hybrid interaction existed for test weight (Table 1). Although all hybrids achieved higher test weights in 2008 than in 2007, this increase was not similar for all hybrids. Most of hybrids significantly increased test weights in 2008 compared to the growing season of 2007 (Fig. 4). However, hybrids Bc354 and PR36K67 had slightly higher test weights in 2008, when compared to their test weights from the previous growing season.

Growing conditions significantly affected ME for pigs (Table 1). Significantly higher ME for pigs were found in the second (2008) year of research when higher test weight, kernel thickness and kernel sphericity were also found (Table 3). Consequently, ME tended to positively correlate with kernel thickness and kernel sphericity. In addition, a significant positive correlation between test weight and ME existed (Table 4). According to Hall (1972), test weight is a highly heritable trait and therefore may be used as an indicator of potential differences between hybrids for ME. Test weights are primarily affected by hybrid type (dent vs. flint) (Stroshine et al., 1986; Grbeša, 2007) but also by growing season (Dale and Jackson, 1994). Baidu et al. (1991) suggested that the increase in test weight is associated with the decrease in ash content, crude fibre and crude protein, but with higher starch content. Furthermore, maize kernels with high test weight are less susceptible to kernel breakage (Peplinski et al., 1992). Very low test weights (<62 kg/hl) may indicate a small starch and oil content (Paulsen et al., 2003), and a smaller proportion of vitreous endosperm (Rutledge, 1978).

Metabolizable energy for pigs averaged 16.67 MJ/kg, which is very similar to the average value of 16.61 for 2634 samples of maize kernels in France (Sauvant et al., 2004). Relatively high ME detected in our research may be partly due to manual harvesting, and consequently, no breakage or foreign material present in kernel samples. It is well known that maize samples consisting of broken kernels and foreign material are characterised by lower ME for poultry (Dale and Jackson, 1994). The largest ME had hybrids Bc 572 (16.86 MJ/kg), Bc 462 (16.85 MJ/kg) and PR34B23 (16.83 MJ/kg). Significantly smaller ME than these three hybrids were determined only for hybrids PR36A24 (16.50 MJ/kg), Bc418B (16.49 MJ/kg) and PR36K67 (16.44 MJ/kg). Hybrid PR36K67 had the highest 1000 kernel weight (Table 2), but the smallest test weight (Table 3). Of all physical properties, test weight showed the strongest positive relationship with ME (r=0,61**) and therefore, these results indicate that it may be used as a simple indicator of ME for commercial maize hybrids. However, our findings once more demonstrated that modern maize hybrids are characterised by very similar ME when produced under intensive agricultural practices in favourable environmental conditions. Previous research showed that about 20% variation in test weights resulted in only 4% variation in ME for poultry (Baidoo et al., 1991).

Conclusions

In spite of similar average 1000-kernel weights, the average test weights varied significantly over two growing seasons. Tested hybrids varied significantly in all kernel physical properties as well as for ME for pigs. Hybrid PR36K67 had high kernel thickness, kernel width and kernel length, and consequently, the heaviest 1000- kernel weight, but the smallest test weight and ME. In contrast, the largest average test weight was found for hybrid Bc 282, which is characterised by the lightest 1000-kernel weights. The highest ME achieved hybrids Bc 572, Bc 462 and PR34B23, while five other hybrids had slightly lower values. Among kernel physical properties of commercial maize hybrids, the test weight appears to be most reliable indicator for assessing ME for pigs.

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