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CHEMICAL COMPOSITION AND NUTRITIONAL VALUE OF MAIZE GRAINS FROM CULTIVARS OF DIFFERENT BREEDING AND SEED COMPANIES

Summary

The study presents the results of field experiments aimed at assessing the level of yield, chemical composition and nutritive value of grain of 32 maize cultivars from different breeding and seed companies. The grain yield, grain chemical composition, fiber fraction content, grain nutritional value, thousand seed weight and grain density were determined to verify the adopted assumptions. The highest content of starch, total protein, fat and nitrogen-free extract compounds was found in the cultivars of the following companies: Limagrain, IGP, Saaten-Union and Maisadour, while the lowest in IGP, Maisadour, Limagrain and IGP, respectively. The energy value of 1 kg dry weight of maize grain for poultry ranged from 14.60 (Maisadour) to 15.22 MJ EM (IGP) and statistically significant differences in the concentration of metabolic energy for poultry was found only in the grain from these companies. Concentration of metabolic energy for pigs ranged from 15.79 (Limagrain) to 15.93 MJ (Saaten-Union) and statistically significant differences in the concentration of metabolic energy for pigs were recorded only in the grain from these companies. Grains from Saaten-Union had a higher concentration of net lactation energy than those from Limagrain and Maisadour. Crude protein, net energy of lactation, sugar, exhaust nitrogenless compounds, weight of one thousand seeds (WTS) and grain density influence on differentiation maize's cultivars.
***Key words**: maize, grain, cultivars, nutritional value, principal component analysis*

SKŁAD CHEMICZNY ORAZ WARTOŚĆ POKARMOWA ZIARNA KUKURYDZY ODMIAN RÓŻNYCH FIRM HODOWLANO-NASIENNYCH

Streszczenie

W pracy przedstawiono wyniki badań polowych, których celem była ocena poziomu plonowania, składu chemicznego oraz wartości pokarmowej ziarna 32 odmian kukurydzy różnych firm hodowlano-nasiennych. Celem weryfikacji przyjętych założeń określono plon ziarna, skład chemiczny ziarna, zawartość frakcji włókna, wartość pokarmową ziarna, masę tysiąca ziaren oraz gęstość ziarna. Największą zawartość skrobi, białka ogólnego, tłuszczu oraz związków bezazotowych wyciągowych stwierdzono w odmianach firm: Limagrain, IGP, Saaten-Union oraz Maisadour, natomiast najniższą odpowiednio w firmach IGP, Maisadour, Limagrain, IGP. Wartość energetyczna 1 kg suchej masy ziarna kukurydzy dla drobiu wahała się od 14,60 (Maisadour) do 15,22 MJ EM (IGP) i tylko w ziarnie pochodzącym z tych firm odnotowano różnice istotne statystycznie w koncentracji energii metabolicznej dla drobiu. Koncentracja energii metabolicznej dla świń wahała się od 15,79 (Limagrain) do 15,93 MJ (Saaten-Union) i tylko w ziarnie pochodzącym z tych firm odnotowano różnice istotne statystycznie w koncentracji energii metabolicznej dla świń. Ziarna z firmy Saaten-Union miały wyższą koncentrację energii netto laktacji niż z firmy Limagrain oraz Maisadour.
***Słowa kluczowe**: kukurydza, ziarno, odmiany, wartość odżywcza, analiza składników*

1. Introduction

The growing interest in cultivating maize for grain in Poland is caused by many reasons, including increased production profitability, with a simultaneous lower profitability of cultivation of other species, grain import limitations and the parallel increase in domestic demand. In addition, this is facilitated by the improvement of the organizational and economic situation of farms, rational mineral fertilization [21], the course of weather conditions favorable to maize yielding and the ease of its cultivation [3]. Maize belongs to species whose economic importance has increased significantly in recent years [1]. This plant is used for food, fodder, or as an energy and industrial raw material [9, 10]. Grain, silage from whole plants or cobs (CCM) and green fodder constitute energy feed for all animal species, mainly for cattle and pigs [5]. Rachids, cob cores, cakes, sprouts or maize dried distillers grains are also used for feed. Maize is also an important raw material for the agri-food industry. Grain is used for the production of maize flour, groats, corn ears or brewing industry and for starch production for the food industry. This species has also been used in the fermentation and distilling industries for the production of consumable alcohol, in the energy industry for biogas production, and in the paper and construction industries [10]. The effects of utilizing biological progress brought by new cultivars depend on technological progress, habitat conditions and farmer's knowledge [15]. New, intensive cultivars will not reveal their production capabilities at low level of agrotechnics and lack of systematic seed exchange [20]. It is estimated that the yield potential of new varieties is utilized in agricultural practice in approximately 50-60%. One of the reasons for this is the lack of a well-functioning system of knowledge dissemination and agricultural advisory services in the country.

The research hypothesis assumed that cultivars of different breeding and seed companies are characterized by a varied yielding level, chemical composition and nutritional value of the grain. Therefore, the aim of the field experiments was to determine the impact of the maize breeding and seed company on the yielding potential of cultivars, chemical composition and nutritional value of the grain.

2. Materials and methods

2.1. Experimental field

The field experiment was carried out in the years 2016-2017 on the fields of the farm "Stadnina Koni Iwno Sp. z o. o.", near Poznań. Maize was sown on April 28. The planned plant density was 7.56 pcs/m^2. Mineral fertilization NPK was carried out in the following amounts: 100 kg N/ha, 80 kg P_2O_5/ha, 120 kg K_2O/ha. The abundance of individual macroelements in the soil before maize sowing was at a moderate level and the pH was 5.9. Weeds were controlled after maize sowing with Lumax 557, 5SE in an amount of 4.0 l/ha. The study evaluated 32 cultivars of fodder maize of five breeding and seed companies (Tab. 1). Thermal and humid conditions in the growing season were favorable for the growth and development of maize.

Table 1. List of tested cultivars
Tab. 1. Wykaz badanych odmian

Cultivars	Breeding and seed companies	FAO
Subito	Saaten-Union	250
Sudrix		260
Suleyka		220/230
Suprime		220/230
Sucampo		230
Surterra		240/250
Korynt		230/240
DS. 1615 (Sundra)		220/230
Davos		230
Suvisio		200/210
DS. 1689 (Suveren)		240/250
Codinan	IGP	220
Codigip		260
Codibird		250
Skalde		240
30.229	Limagrain	240
32.58		250
31.233		240
Paullen		260
Mas 26B	Maisadour	250
Mas 20F		230
Mas 22R		240
DM 2023		230/240
Mas 29T		270
Borgi	Caussade	230/240
Skolli		230
Rianni		240
Bacari		250
Herkuli		260/270
Borelli		250/260
Asteri		230/240
Telesto		230

Source: own work / Źródło: opracowanie własne

2.2. Laboratory assays

Grain samples were ground in a mill (SM 100, Retsch) to a particle size of 1 mm. The content of basic nutrients (crude ash, crude protein, crude fat and crude fiber) [2], fiber fraction (neutral-detergent fiber, NDF; acid-detergent fiber, ADF and acidic lignin, ADL), sugar [2] and starch [PN-R-64785] were determined in such fragmented samples [22]. Nutritional value of grain for cattle is given in net lactation energy (DLG 2001), for poultry in metabolic energy [18] and for pigs in metabolic energy [6].

2.3. Statistical analysis

Firstly, the normality of distribution for studied traits was tested using the Shapiro-Wilk normality test [19]. A one-way analysis of variance (ANOVA) was performed to verify the hypothesis of a lack of effects of breeder on the variability of observed traits. Mean values and standard deviations of individual traits were calculated for each breeder. Least significant differences (LSDs) for each trait were calculated. Homogeneous groups (not significantly different from each other) for the analyzed traits were determined on the basis of LSDs. The Bonferroni correction was used for multiple testing while performing multiple comparisons. A one-way ANOVA was performed to verify the hypothesis of a lack of effects of FAO number on the variability of observed traits. The relationships between observed traits were estimated using Pearson's correlation coefficients [8]. Results were also analysed using multivariate methods. The principal component analysis was applied in order to present multitrait assessment of similarity of tested cultivars in a lower number of dimensions with the least possible loss of information [14]. The simple correlation coefficients between the values of the first two principal components and the values of particular original traits were estimated to evaluation of relative share of each original trait in the multi-trait variability of the examined cultivars. Data analysis was performed using the statistical package GenStat 18.

3. Results and discussion

All studied traits have a normal distribution. The results of ANOVA indicate that the main effect of breeder was significant for crude protein, crude fat, net energy of lactation, sugar, grain yield and grain density (Tab. 2). Starch is the basic component of maize grain. In the evaluated cultivars, starch constituted from 70.67% (IGP) to 72.01% (Limagrain) of dry weight, however, there were no statistically significant differences in the amount of this component between the studied breeding and seed companies. Idikut et al. [7] and Podkówka et al. [12] reported similar, and Li et al. [11] and Radosavljević et al. [13] higher concentration of starch in the maize grain. There were statistically significant differences in the concentration of total protein in the grain of evaluated breeding and seed companies ($p \le 0.05$). Maisadour cultivars had the lowest concentration of total protein (8.17%), and IGP the highest (10.88%) (Tab. 3). Idikut et al. [7], Li et al. [11] and Radosavljević et al. [13] reported similar, and Podkówka et al. [12] found higher content of total protein in grain dry weight. The conducted experiment showed a high negative correlation ($p \le 0.001$) between the concentration of total protein and BNW and sugar (Tab. 4).

Table 2. Mean squares from one-way (breeder) analysis of variance for observed traits

Tab. 2. Średnie kwadraty z jednoczynnikowej (hodowlanej) analizy wariancji dla obserwowanych cech

Source of variation	Breeder	Residual
Number of degrees of freedom	4	27
Crude ash (% DM)	0.01119	0.01958
Crude protein (% DM)	4.2863***	0.541
Crude fat (% DM)	0.546*	0.1971
Crude fibre (% DM)	0.04805	0.06276
Exhaust nitrogenless compounds (% DM)	4.7494**	0.9522
NDF (% DM)	1.7648	0.7887
ADF (% DM)	0.4051	0.1942
Starch (% DM)	1.319	1.442
Sugar (% DM)	0.00137*	0.0004933
Metabolic energy - poultry	0.2979	0.1901
Metabolic energy - swine	0.017399	0.009607
Net energy of lactation (MJ/kg SM)	0.0008737	0.0007502
Grain in Mass Ears	1.0181	0.5416
Grain Yield	3.202*	1.054
WTS	1262.8	735.9
Grain Density	9.603*	2.841
* P<0.05; ** P<0.01; *** P<0.001		

Source: own work / Źródło: opracowanie własne

However, no correlation was found between the concentration of total protein and starch, while Idikut et al. [7] reported that it was very high (r = -0.916, p≤0.01). Saaten-Union grains had a higher crude fat content in dry weight than grains from Limagrain (p≤0.05). No statistically significant differences were found in the amount of this component in grains from other seed companies. Podkówka et al. [12] found similar, and Radosavljević et al. [13] higher fat content in grain dry weight. The level of this component in maize grain was negatively correlated with the amount of nitrogen-free extract compounds (r = -0.61, p≤ 0.001) (Tab. 4). There were no statistically significant differences in the concentration of crude ash and crude fiber in the grain between the studied breeding and seed companies. Other authors [12, 13] reported a similar content of both components in dry weight of maize grains. The content of nitrogen-free extract compounds in grain dry weight ranged from 80.97 (IGP) to 83.63% (Maisadour). BNW concentration in the grain from the Maisadour seed company was higher than in grain from Caussade, IGP and Saaten-Union (p≤0.05). Podkówka et al. [12] found higher content of BNW in dry weight than in our research. The grain from IGP and Maisadour had a lower concentration of neutral detergent fiber than from Saaten-Union (p≤0.05). No statistically significant differences were found in the amount of this component in grains from other seed companies.

Table 3. Mean values and standard deviations for observed traits classified by breeder

Tab. 3. Wartości średnie i odchylenia standardowe dla obserwowanych cech w zależności od firmy hodowlanej

Breeder	Crude ash (% DM)		Crude protein (% DM)		Crude fat (% DM)		Crude fibre (% DM)	
	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.
Caussade	1.48a	0.171	9.82a	0.508	4.47ab	0.4505	2.21a	0.1549
IGP	1.52a	0.1395	10.88a	1.4438	4.58ab	0.3099	2.06a	0.2142
Limagrain	1.47a	0.1273	9.62a	0.2333	4.06b	0.4795	2.23a	0.1459
Maisadour	1.42a	0.1274	8.17c	0.3176	4.45ab	0.1576	2.33a	0.1069
Saaten-Union	1.52a	0.1233	9.55a	0.7733	4.87a	0.5313	2.27a	0.3577
$LSD_{0.05}$	0.17		0.88		0.53		0.3	
Breeder	Exhaust nitrogenless compounds (% DM)		NDF (% DM)		ADF (% DM)		Starch (% DM)	
	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.
Caussade	82.02bc	0.767	7.68ab	0.6353	1.71ab	0.5095	70.73a	1.081
IGP	80.97c	1.6018	7.27b	1.2367	1.84ab	0.4789	70.67a	0.895
Limagrain	82.62ab	0.5537	7.45ab	0.8703	1.59b	0.4078	72.01a	1.165
Maisadour	83.63a	0.2816	7.33b	1.2491	2.21a	0.1576	71.24a	1.015
Saaten-Union	81.79bc	1.125	8.42a	0.7328	1.56b	0.4627	71.03a	1.42
$LSD_{0.05}$	1.17		1.06		0.53		1.44	
Breeder	Sugar (% DM)		Metabolic energy - poultry (MJ/kg SM)		Metabolic energy - swine (MJ/kg SM)		Net energy of lactation (MJ/kg SM)	
	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.
Caussade	1.95bc	0.0131	14.90ab	0.483	15.87ab	0.0994	8.29a	0.0275
IGP	1.94c	0.0208	15.22a	0.5486	15.90ab	0.0556	8.30a	0.0126
Limagrain	1.98a	0.0129	15.09ab	0.4857	15.79b	0.0686	8.28a	0.0129
Maisadour	1.97ab	0.0152	14.60b	0.3087	15.87ab	0.0483	8.28a	0.0114
Saaten-Union	1.95bc	0.0307	15.09ab	0.3883	15.93a	0.1256	8.31a	0.0367
$LSD_{0.05}$	0.027		0.52		0.12		0.033	
Breeder	Grain in Mass Ears		Grain Yield		WTS		Grain Density	
	Mean	s.d.	Mean	s.d.	Mean	s.d.	Mean	s.d.
Caussade	87.62ab	0.7274	13.84a	1.008	327.0ab	31.06	76.79ab	1.688
IGP	87.11b	0.9687	12.37b	1.357	342.9ab	53.29	77.53a	1.83
Limagrain	87.34ab	0.7087	12.97a	0.949	359.1a	14.96	74.50c	2.189
Maisadour	87.47ab	0.5994	12.29b	0.632	315.8b	16.03	74.56c	1.553
Saaten-Union	88.11a	0.7184	13.68a	1.073	338.4ab	17.02	75.15bc	1.506
$LSD_{0.05}$	0.88		1.23		32.5		2.02	

Source: own work / Źródło: opracowanie własne

Table 4. Correlation coefficients for observed traits

Tab. 4. Współczynniki korelacji dla obserwowanych cech

Trait	Crude ash	Crude protein	Crude fat	Crude fibre	Exhaust nitrogenless compounds	NDF	ADF	Starch	Sugar	Metabolic energy - poultry	Metabolic energy - swine	Net energy of lactation	Grain in Mass Ears	Grain Yield	WTS
Crude protein	0.17														
Crude fat	0.04	0.22													
Crude fibre	-0.2	-0.35*	0.06												
Exhaust nitrogenless compounds	-0.23	-0.88***	-0.61***	0.09											
NDF	-0.03	0.05	0.09	-0.04	-0.06										
ADF	-0.32	-0.21	0.19	-0.07	0.15	0.04									
Starch	-0.04	-0.25	-0.22	0.07	0.3	-0.52**	-0.1								
Sugar	-0.1	-0.66***	-0.52**	0.06	0.77***	-0.37*	0	0.83***							
Metabolic energy - poultry	0.12	0.50**	0.39*	-0.14	-0.57***	-0.38*	-0.2	0.60***	0.07						
Metabolic energy - swine	-0.1	0.26	0.93***	-0.26	-0.54**	0.1	0.29	-0.22	-0.47**	#					
Net energy of lactation	-0.36*	0.36*	0.83***	0.31	-0.67***	0.1	0.18	-0.22	-0.57***	0.39*	0.75***				
Grain in Mass Ears	0.14	-0.24	-0.05	0.3	0.14	0.23	-0.1	0.23	0.24	0.04	-0.18	-0.08			
Grain Yield	-0.16	0.21	0.09	-0.02	-0.19	0.35*	-0.2	-0.13	-0.2	0.05	0.11	0.2	0.46		
WTS	0.13	0.50**	-0.2	-0.33	-0.29	-0.02	-0.3	0.18	-0.01	0.38*	-0.12	-0.1	-0.16	-0.02	
Grain Density	-0.14	0.43*	0.1	-0.17	-0.35*	0.03	0	-0.2	-0.32	0.13	0.17	0.21	-0.22	-0.09	-0.1
* P<0.05; ** P<0.01; *** P<0.001 # - correlation coefficient not calculated															

Source: own work / Źródło: opracowanie własne

Li et al. [11], Radosavljević et al. [13] and Zilic et al. [23] re-C corded higher concentrations of starch in maize grain. In our study, negative correlations between the concentration of NDF and starch in the grain were found (r = -0.52, p≤0.01), while Li et al. [11] did not find such a dependence. The grain from Saaten-Union oraz Limagrain had a lower concentration of acidic detergent fiber than from Maisadour (p≤0.05). No statistically significant differences were found in the amount of this component in grains from other breeding and seed companies. In our study, the content of ADF in dry weight was lower than that reported by Li et al. [11], Radosavljević et al. [13] and Zilic et al. [23]. Radosavljević et al. [13] showed that the correlation between the concentration of NDF and ADF was 0.65 and was statistically significant (p≤0.05). Such relationship was not found in our study and the work Li et al. [11]. The energy value of 1 kg dry weight of maize grain for poultry ranged from 14.60 (Maisadour) to 15.22 MJ EM (IGP) and statistically significant differences (p≤0.05) in the concentration of metabolic energy for poultry were found only in the grain from these companies. Podkówka et al. [12] reported lower concentration of metabolic energy for poultry in maize grain. The energy value of maize for poultry was strongly correlated with the total protein content in the grain (r = 0.50, p≤0.01), BNW (r = 0.57, p≤0.001) and starch (r = 0.60; p≤0.001). The concentration of metabolic energy for pigs ranged from 15.79 (Limagrain) to 15.93 MJ (Saaten-Union) and statistically significant differences (p≤0.05) in the concentration of metabolic energy for pigs were found only in the grain from these companies. The energy value of maize for pigs was strongly correlated with crude fat in the grain (r = 0.93, p≤0.001), BNW (r = -0.54, p≤0.01) and sugar (r = -0.47; p≤0.01). Grains from Saaten-Union had a higher concentration of net lactation energy than those from Limagrain and Maisadour. No statistically significant differences were found in the amount of this component in grains from other seed companies. The energy value of maize for cattle was strongly correlated with crude fat in the grain (r = 0.83, p≤0.001), BNW (r = -0.67, p≤0.001) and sugar (r = -0.57; p≤0.001). The differences between mean values of all observed traits for different FAO number were not statistically significant (Tab. 5).

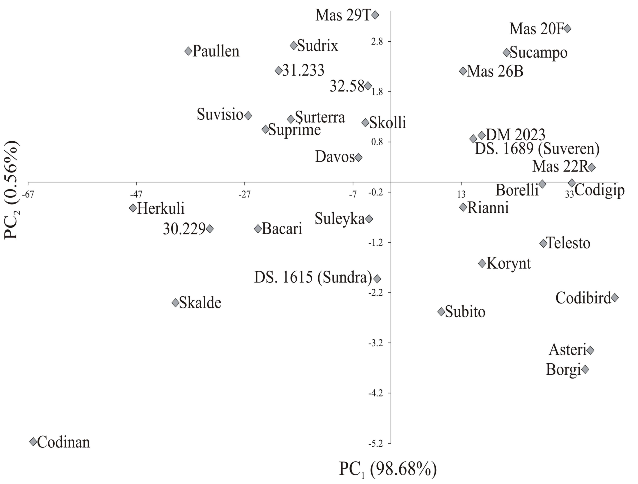
Table 5. Mean squares from one-way (FAO number) analysis of variance for observed traits

Tab. 5. Średnie kwadraty z jednoczynnikowej (liczba FAO) analizy wariancji dla obserwowanych cech

Source of variation	FAO number	Residual
Number of degrees of freedom	12	19
Crude ash (% DM)	0.02743	0.01286
Crude protein (% DM)	1.2253	0.8973
Crude fat (% DM)	0.2963	0.2078
Crude fibre (% DM)	0.05441	0.06494
Exhaust nitrogenless compounds (% DM)	1.287	1.54
NDF (% DM)	1.1117	0.7902
ADF (% DM)	0.304	0.1693
Starch (% DM)	1.866	1.148
Sugar (% DM)	0.0006444	0.0005825
Metabolic energy - swine	0.2854	0.1526
Metabolic energy - poultry	0.013469	0.008809
Net energy of lactation (MJ/kg SM)	0.0008438	0.0007171
Grain in Mass Ears	0.5194	0.656
Grain Yield	1.724	1.083
WTS	1077.8	630.9
Grain Density	5.383	2.659

Source: own work / Źródło: opracowanie własne

Individual traits are of different importance and have a different share in the joint multivariate variation. A study on the multivariate variation for treatments includes also identification of the most important traits in the multivariate variation of treatments. Principal component analysis is a statistical tool making it possible to solve this problem [17, 16]. Results of the principal component analysis for investigated cultivars were presented in Fig. 1 and Tab. 6. The first two principal components explained jointly 99.24% of total variation between cultivars (Tab. 6, Fig. 1). In the graph the coordinates of a point of a given treatment are values of the first and second principal components, respectively. The greatest, significant linear relationship with the first principal component was found for crude protein, ME_p and WTS (negative dependencies) (Tab. 6). The second principal component was significantly positively correlated with net energy of lactation and sugar, however negatively correlated with crude protein, exhaust nitrogenless compounds and grain density (Tab. 6).



Source: own work / Źródło: opracowanie własne

Fig. 1. Location of maize (*Zea mays* L.) cultivars in the space of first two principal components
Rys. 1. Rozmieszczenie odmian kukurydzy (Zea mays L.) w układzie dwóch pierwszych składowych głównych

Table 6. Results of discriminatory analysis
Tab. 6. Wyniki analizy dyskryminacyjnej

Trait	PC_1	PC_2
Crude ash (% DM)	-0.126	0.034
Crude protein (% DM)	-0.500**	-0.684***
Crude fat (% DM)	0.197	-0.288
Crude fibre (% DM)	0.331	0.207
NfE (% DM)	0.286	0.648***
NDF (% DM)	0.019	-0.121
ADF (% DM)	0.345	0.04
Starch (% DM)	-0.178	0.401*
Sugar (% DM)	0.012	0.623***
ME_p	-0.378*	-0.203
ME_s	0.121	-0.336
NEL	0.103	-0.399*
Grain in Mass Ears	0.162	0.281
Grain Yield	0.023	-0.021
WTS	-1.000***	0
Grain Density	0.102	-0.927***
* P<0.05; ** P<0.01; *** P<0.001		

Source: own work / Źródło: opracowanie własne

4. Conclusions

The highest content of starch, total protein, fat and nitrogen-free extract compounds was found in the cultivars of the following companies: Limagrain, IGP, Saaten-Union and Maisadour, while the lowest in IGP, Maisadour, Limagrain and IGP, respectively. There were no statistically significant differences in the concentration of crude ash and crude fiber in the grain of cultivars between the studied breeding and seed companies. The grain from IGP and Maisadour had a lower concentration of neutral detergent fiber than from Saaten-Union. The grain from Saaten-Union and Limagrain had a lower concentration of acidic detergent fiber than from Maisadour. The energy value of 1 kg dry weight of maize grain for poultry ranged from 14.60 (Maisadour) to 15.22 MJ EM (IGP) and statistically significant differences in the concentration of metabolic energy for poultry were found only in the grain from these companies. The concentration of metabolic energy for pigs ranged from 15.79 (Limagrain) to 15.93 MJ (Saaten-Union) and statistically significant differences in the concentration of metabolic energy for pigs were found only in the grain from these companies. Grains from Saaten-Union had a higher net concentration of lactation energy than from Limagrain and Maisadour. Crude protein, net energy of lactation, sugar, exhaust nitrogenless compounds, WTS and grain density influence on differentiation of maize cultivars.

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