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The nutritive value of maize cultivars for broiler chickens

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ABSTRACT

The objective of the study was to determine the nutritive value of grain of different maize cultivars for broiler chickens. The study involved 45 Ross 308 broilers (9 groups with 5 chickens per group) aged 42 to 49 days. Chickens were fed the grain of maize cultivars Pioneer PR39H84, Smok, Arobase, Moncada, Pioneer PR39G12, Eurostar, Opoka, Boruta, and Nysa *ad libitum*. The cultivars of maize differed in basic chemical composition, contents of amino acid and fibre fractions, as well as fatty acid profiles. Variations in chemical composition among different maize cultivars had an effect on the extent of basic nutrient digestion and on the energy value of grain in broiler chickens. For practical utilization of maize in broiler feed mixtures it will be important to determine the content of insoluble fibre, as it is negatively correlated with nutrient digestibility and the AME_N value of grain (r=-0.69; P<0.05).

KEY WORDS: broiler chickens, maize cultivars, digestibility, amino acids, AME_N

INTRODUCTION

Maize (*Zea mays* L.) is one of the main components of broiler diets. Tables on the composition and nutritional value of feedstuffs (Sauvant et al., 2004; Smulikowska and Rutkowski, 2005) usually contain only average values for components of

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maize, thus assuming slight varietal differences. As a result of advances in plant breeding, driven by competition in the cultivar market, differences in chemical composition among cereal varieties of the same species can be greater than those between different cereal species, and this fact is not accounted for in the nutrient requirements for poultry (Lasek et al., 2011).

Song et al. (2003) reported that maize cultivars may differ not only in the content of protein but also in their starch and fibre contents, as well as in nutrient digestibility and metabolizable energy (AME_N). According to Cowieson (2005) maize may contain from 71 g to 94 g of crude protein per kg, which is less than in wheat or barley. The most important storage protein in maize is zein, which is poor in the essential amino acids, tryptophan and lysine, thus, the protein value of maize is also poor.

The AME_N value of maize for poultry is higher than other cereals due to its relatively high starch (620 to 720 g/kg) and crude fat (34 to 52 g/kg) contents. It may differ, however, depending on the level of amylose in starch (Svihus et al., 2005), the amylose : amylopectin ratio, the encapsulation of starch, and the presence of different antinutrients, primarily, phytate, enzyme inhibitors, and resistant starch (Cowieson, 2005).

The aim of the study was to determine the nutritive and energy value of different maize cultivars in broiler chickens.

MATERIAL AND METHODS

Maize cultivars

The grain of nine maize cultivars varying in chemical or physical traits: flint (Pioneer PR39H84), semiflint (Smok, Arobase, Moncada, Pioneer PR39G12), semiflint/semident (Eurostar), and semident (Opoka, Boruta, Nysa) was investigated. All maize cultivars (cvs) were grown at Brzezinka (Małopolska, Poland) at the same field and growing conditions and were harvested in 2005.

Animals, feeding and management

A digestibility trial was performed on a single batch of each cultivar in 2006 by standard methods using 45 Ross 308 chickens (9 groups with 5 birds per group) aged 42 days. Before the digestibility trial, the chickens were kept in pens and fed a standard broiler starter diet from 0 to 14 d of life, then from 14 to 42 d of life they were kept in individual cages and fed diets based on the evaluated maize cvs and containing ($g \cdot kg^{-1}$): maize 708.5, soyabean meal 180, fish meal 80, monocalcium phosphate 5, limestone 11, L-lysine 4.7, DL-methionine 2.8, vitamin-mineral premix 5, to satisfy nutrient requirements of broilers according to Smulikowska and Rutkowski (2005).

During the digestibility trial the birds were kept individually in balance cages with free access to feed and water. Chickens received only coarsely ground grain of the respective maize cultivars on an *ad libitum* basis. The experiment lasted 7 d including 4 days of adaptation, and 3 days of excreta collection. Feed intake was measured (it averaged 141.4 g/day, ± 13.8 g) and excreta from each bird were quantitatively collected twice a day from trays placed under the cages, pooled and kept frozen at -18°C until analysis. After the end of the experiment the chickens were killed, the abdomen was opened and the gastrointestinal tract was excised. The jejunal digesta (from the end of the duodenum to Meckel's diverticulum) was collected and pH and viscosity were immediately measured. All procedures were approved by the Local Animal Care and Use Committee.

Chemical analyses

The chemical composition, including amino acids, fatty acids, starch, sugars, crude and dietary fibre fractions in maize grain, was analysed. The chemical composition of maize grain and excreta was determined according to AOAC (2005), while α-amino nitrogen in feed and excreta was determined according to method of Pahle et al. (1983) modified by Barteczko et al. (1993). The method is based on the hydrolysis of protein in feed and faeces in hydrochloric acid. After hydrolysis and distillation, ninhydrin solution was added and absorbance was determined at a wavelength of λ = 411 nm on a UNICOM UV/VIS 8675 spectrophotometer. The content of gross energy (GE) in maize grain and excreta was measured using a Parr adiabatic oxygen bomb calorimeter (KL-10, Precyzja, Bydgoszcz, Poland). The amino acid composition of maize grain and excreta was determined by liquid chromatography using an INGOS AAA-400 amino acid analyser (Prague, Czech Republic), equipped with an Ostion LG ANB (370 mm) column. Column temperature was 55°C, reactor temperature 120°C, detection wavelengths 440 and 570 nm. In maize grain the contents of neutral detergent fibre (NDF), acid detergent fibre (ADF), and acid detergent lignin (ADL) were determined using an ANKOM220 Fiber Analyser (Ankom Products, NY, USA) according to AOAC (2005), whereas soluble (SDF) and insoluble (IDF) dietary fibres were analysed by an enzymatic method according to Englyst and Cummings (1988). The starch content in maize grain was determined by an enzymatic method with α-amylase according to Faisant et al. (1995), whereas amylose and amylopectin in starch, by the method of Morrison and Laignelet (1983). Total sugars were determined by a spectrophotometric method according to Zagrodzki et al. (1969), using a colour reaction with anthron mixed with pure concentrated H_2SO_4. Before measurement the samples were deproteinized using a solution of $Zn(CHCOO)_2 \cdot H_2O$ 275.12 g/l and $K_4Fe(CN_6) \cdot 3H_2O$ 171.99 g/l distilled water. Absorbance was measured at a wavelength of $\lambda = 620$ nm.

The composition of fatty acids was determined using a gas chromatograph (Varian Star 3400CX) with a flame-ionization detector and DB-23 column (30 m long × 0.5 mm in diameter), column temperature 100°C-205°C, injector temperature 200°C, detector temperature 240°C.

In jejunal digesta, the pH was measured using a MERA ELWRO N 517 pH meter (Poland), the digesta was centrifuged for 10 min at 10000 *g* in 4°C and the viscosity of the supernatant was measured with the use of a capillary tube at 37.5°C and calculated relative to the viscosity of water.

Calculations and statistical analysis

The apparent total tract digestibility (ATTD) of dry matter, organic matter, crude fat, N-free extractives, and amino acids was calculated from analytical data and the quantitative measurement of feed intake and excreta output. The ATTD of protein was calculated according to Pahle et al. (1983) with the use of α-amino nitrogen determined in feed and excreta. Apparent metabolizable energy corrected to zero nitrogen balance (AME_N) was calculated according to the formula of Hill and Anderson (1958):

$$AME_N = AME - (BN\ g \times 0.0365)$$

where: BN (N retained), g = N intake, g - N excreta, g

Means were compared for main effects using one-way analysis of variance and Tukey's test. Pearson's correlation coefficients were calculated as a measure of the strength of the association between variables (Statistica, 2005). The differences were considered significant at $P<0.05$.

RESULTS

The nutrient content of maize grain varied according to cultivar (Table 1). The maximum difference in crude protein (CP) content among the cultivars was 4.6 percentage units. The cultivars also differed considerably in the content of crude fat (CF). The Opoka and Eurostar cvs had the highest CF content, about 2.5 times that of Pioneer PR39H84. The maximum difference in starch content among cultivars was 10 percentage units. Maize grain differed in water-soluble carbohydrate content, with maximum differences of 6.2 g/kg DM among the cultivars. Arobase cv had the least crude fibre of all cultivars, with the lowest NDF, ADF, and SDF contents. Maize cvs differed in gross energy content (maximum 0.27 MJ).

Table 1. Chemical composition of maize grain. $g \cdot kg^{-1}$ DM; gross energy value (GE) $MJ \cdot kg^{-1}$ DM

Components	Maize cultivars									Mean	SEM
	Smok	Nysa	Opoka	Boruta	Arobase	Pioneer PR39G12	Eurostar	Pioneer PR39H84	Moncada		
Dry matter, $g \cdot kg^{-1}$	888	882	881	888	871	871	870	876	878	878	6.8
	$g \cdot kg^{-1}$ DM										
Organic matter	984	986	986	988	987	988	987	989	985	987	1.56
Crude ash	16.0	14.4	14.4	12.3	13.3	12.2	12.8	11.1	14.9	13.5	1.56
Crude protein	137	130	127	110	100	99.0	93.4	90.6	90.4	108	18.1
Crude fat	37.5	45.3	50.2	46.6	47.3	46.5	50.0	19.4	27.2	41.1	10.9
Crude fibre	22.3	18.5	26.0	20.1	16.5	24.4	21.8	21.7	24.0	21.7	2.99
N-free extractives	788	792	782	811	823	818	822	857	843	815	25.2
Starch	680	675	665	678	725	766	744	757	753	716	40.9
Amylose	220	215	214	229	226	214	212	223	219	219	5.82
Amylopectins	460	460	450	449	499	552	532	533	534	497	42.0
Amylose in starch	32.3	31.9	32.3	33.8	31.1	28.0	28.5	29.5	29.1	30.7	2.01
Sugars	16.1	18.0	15.0	30.8	12.1	14.6	16.0	12.7	8.0	15.9	6.29
ADF (acid detergent fibre)	46.1	44.9	65.4	47.5	39.9	53.5	47.4	45.6	48.8	48.8	7.17
ADL (acid detergent lignin)	5.63	8.84	12.1	8.77	7.69	14.7	6.32	8.10	8.65	8.98	2.82
NDF (neutral detergent fibre)	156	117	159	136	104	117	155	137	140	136	19.6
IDF (insoluble dietary fibre)	94.1	100	107	92.5	96.8	84.8	107	102	119	101	10.1
SDF (soluble dietary fibre)	6.31	7.71	8.96	7.29	3.56	9.18	8.85	8.44	7.52	7.54	1.76
TDF (total dietary fibre)	100	108	116	100	100	94.0	116	111	127	108	10.4
GE, $MJ \cdot kg^{-1}$ SM	18.8	18.7	18.9	18.8	18.6	19.0	19.1	18.6	18.3	18.7	0.26

analyses were made in duplicate

Maize cvs also differed in amino acid content (Table 2). Crude fat was composed mostly of unsaturated fatty acids (Table 3). The largest differences among cultivars were found for oleic (10%) and linoleic acids (13.9%). Arobase and Moncada cvs had the highest content of polyunsaturated fatty acids (PUFA). All maize cultivars were characterized by a high, but varied n-6/n-3 PUFA ratio ranging from 25 to 44 (Table 3).

The ATTD of the main nutrients in chickens varied significantly ($P<0.05$) among cultivars (Table 4). The highest coefficients of CP digestibility were determined in Boruta and Arobase maize, and the lowest, in cv Moncada (8.9 percentage units; $P<0.05$). The ATTD of crude fat averaged 67.4%, with within-cultivar deviations of ±15.4 ($P<0.05$); the lowest values were found for Pioneer PR39H84 and Moncada cvs. The ATTD of starch averaged 99%, the lowest values were found for Arobase cv ($P<0.05$). The pH values of jejunal digesta averaged 5.8, the difference between Arobase cv and Pioneer PR39H84 cv was statistically significant (Table 4). The jejunal digesta viscosity averaged 1.82 and did not differ between cultivars.

The maize cvs differed ($P<0.05$) in AME_N value (Table 4). The lowest AME_N value was found in Pioneer PR39H84 cv and was 1.44 MJ lower compared with that determined for Pioneer PR39G12 cv.

The amino acids of Boruta, Nysa, Smok and Arobase cvs were digested better compared with the low-protein cvs Eurostar, Pioneer PR39G12, Pioneer PR39H84, and Moncada (Table 5). Among essential amino acids, the ATTD averaged from 72% for lysine to 91.4% for leucine, with lysine digestibility being more variable than the other essential amino acids (Table 5).

The IDF in maize was negatively correlated with sugar content as well as with organic matter and crude fat digestibility and with AME_N value ($P<0.05$), while the SDF was positively correlated with the pH of jejunal digesta (data not shown), starch digestibility, and AME_N value (Table 6). There was a positive correlation of digesta pH with its viscosity ($r = 0.61$; $P<0.05$) and negative correlation with crude fat digestibility ($r = 0.45$; $P<0.05$). The ATTD of organic matter and crude fat was positively correlated with the content of sugars in grain. Neither pH nor viscosity of jejunal digesta affected digestibility of nutrients. AME_N value was negatively correlated with IDF and positively with SDF and sugar content in maize grain, as well as positively correlated with the digestibility of organic matter, crude protein, crude fat, and starch (Table 6).

Table 2. Content of amino acids in maize grain, $g \cdot kg^{-1}$ DM

Amino acids	Maize cultivars									Mean	SEM
	Smok	Nysa	Opoka	Boruta	Arobase	Pioneer PR39G12	Eurostar	Pioneer PR39H84	Moncada		
Lys	2.35	3.15	2.82	3.43	2.36	2.47	2.65	2.60	1.97	2.67	0.43
Met	2.40	1.81	1.97	2.26	1.42	1.54	1.60	1.22	1.43	1.73	0.42
Cys	2.51	2.45	2.21	2.55	1.68	1.89	2.06	1.56	1.73	2.09	0.39
Thr	3.89	4.32	3.99	4.58	3.05	3.73	3.28	3.36	2.62	3.66	0.62
Trp	0.08	0.08	0.07	0.07	0.06	0.06	0.06	0.06	0.06	0.84	0.15
Arg	4.73	5.98	5.23	6.64	4.26	4.14	4.57	4.39	3.41	4.81	0.98
His	3.42	3.68	3.49	3.71	2.83	2.74	2.86	2.57	2.23	3.06	0.54
Ile	3.30	3.50	3.99	3.25	2.30	2.65	2.93	2.60	1.99	2.96	0.63
Leu	16.5	16.4	16.3	13.9	10.9	11.7	10.9	10.7	8.4	12.9	3.01
Phe	6.14	6.20	6.12	5.60	4.14	4.26	4.08	4.04	3.23	4.86	1.14
Tyr	4.52	4.95	3.74	4.08	3.00	2.86	3.24	3.34	2.59	3.59	0.80
Val	4.85	5.09	5.60	5.09	3.51	4.13	4.59	4.19	3.14	4.47	0.81
Ala	9.75	9.43	9.46	9.06	6.74	7.87	6.76	6.66	5.39	7.92	1.59
Asp	7.42	8.09	7.60	8.69	5.71	7.42	6.19	6.50	4.87	6.94	1.21
Glu	26.8	23.6	23.0	22.7	18.6	18.5	16.2	15.9	13.8	19.9	4.30
Gly	3.67	4.23	3.78	4.64	3.01	3.67	3.45	3.32	2.57	3.60	0.60
Pro	9.55	13.38	12.48	11.30	7.04	9.64	9.99	8.78	6.06	9.81	2.38
Ser	6.03	6.36	5.71	6.40	4.52	5.42	4.24	4.46	3.49	5.18	1.04

analyses were made in duplicate

Table 3. Major fatty acids in maize grain lipids, % of total fatty acids

Fatty acids	Maize cultivars									Mean	SEM
	Smok	Nysa	Opoka	Boruta	Arobase	Pioneer PR39G12	Eurostar	Pioneer PR39H84	Moncada		
C 14:0	0.18	0.26	0.30	0.29	0.20	0.28	0.19	0.25	0.24	0.26	0.05
C 16:0	12.2	13.8	12.7	13.0	12.6	15.1	14.3	15.2	12.1	13.4	1.20
C 16:1	0.29	0.55	0.52	0.49	0.18	0.55	0.94	1.14	0.42	0.57	0.28
C 18:0	3.30	4.90	3.43	3.38	2.59	4.76	3.99	0.97	2.88	3.37	1.18
C 18:1	31.9	33.8	35.5	37.4	29.0	32.9	39.0	33.6	30.5	33.7	3.19
C 18:2	49.5	44.3	45.3	42.9	53.2	44.3	39.3	42.7	51.4	45.9	4.54
C 18:3	1.57	1.00	1.17	1.74	1.46	1.41	1.40	1.21	1.46	1.39	0.22
SFA	15.7	19.0	16.4	16.6	15.4	20.1	18.5	16.4	15.2	17.0	1.74
UFA	83.3	79.7	82.5	82.5	83.8	79.2	80.7	78.7	83.8	81.6	2.02
MUFA	32.1	34.4	36.0	37.9	29.2	33.5	39.9	34.7	30.9	34.3	3.36
PUFA	51.1	45.3	46.5	44.6	54.6	45.7	40.7	44.0	52.9	47.3	4.58
n–6/ n–3	31 : 1	44 : 1	39 : 1	25 : 1	36 : 1	31 : 1	28 : 1	35 : 1	35 : 1	34 : 1	5.50

SFA - saturated fatty acids; UFA - unsaturated fatty acids; MUFA - monounsaturated fatty acids; PUFA - polyunsaturated fatty acids; analyses were made in duplicate

Table 4. Apparent total tract nutrients digestibility (% of intake), apparent metabolizable energy value and some jejunal digesta parameters in broilers

Indices	Maize cultivars									Mean	SEM
	Smok	Nysa	Opoka	Boruta	Arobase	Pioneer PR39G12	Eurostar	Pionier PR39H84	Moncada		
Dry matter	83.5^{ab}	83.4^{ab}	81.2^{a}	84.7^{b}	81.6^{a}	86.0^{b}	83.0^{ab}	83.7^{ab}	81.0^{a}	83.1	1.66
Organic matter	85.8^{ab}	85.6^{ab}	83.7^{a}	86.8^{b}	83.8^{a}	88.0^{b}	85.4^{ab}	85.9^{ab}	83.5^{a}	85.4	1.50
Crude protein	81.4^{b}	79.5^{ab}	78.9^{ab}	82.1^{b}	82.0^{b}	75.8^{ab}	78.3^{ab}	77.1^{ab}	73.2^{a}	78.7	3.01
Crude fat	68.1^{c}	70.8^{bc}	77.2^{bd}	73.8^{bcd}	74.9^{bcd}	80.4^{d}	78.9^{d}	41.4^{a}	40.9^{a}	67.4	15.4
Starch	99.6^{b}	99.2^{b}	99.7^{b}	98.8^{ab}	97.3^{a}	98.7^{ab}	99.1^{ab}	98.7^{ab}	98.2^{ab}	98.8	0.73
AME_N MJ/kg	13.9^{cd}	13.7^{bcd}	13.5^{bd}	13.9^{cd}	13.1^{ab}	14.2^{c}	13.8^{cd}	12.8^{a}	13.6^{bcd}	13.6	0.43
AME_N/GE. %	82.5^{abc}	81.4^{abc}	79.8^{ab}	83.2^{abc}	79.6^{ab}	86.0^{c}	83.8^{abc}	78.9^{a}	83.7^{abc}	82.8	1.80
Jejunal digesta pH	5.78^{ab}	5.73^{ab}	5.87^{ab}	5.74^{ab}	5.63^{a}	5.74^{ab}	5.76^{ab}	6.00^{b}	5.86^{ab}	5.79	0.03
Jejunal digesta viscosity, cPs·s	1.87	1.71	1.94	1.74	1.72	1.73	1.91	1.90	1.86	1.82	0.03

AME_N - apparent metabolizable energy corrected to zero nitrogen balance; GE - gross energy

$^{a, b, c}$ - means in rows with different letters differ significantly at $P<0.05$

Table 5. Apparent total tract digestibility of amino acids (% of intake) of maize cultivars in broiler, %

Amino acids	Maize cultivars									Mean	SEM
	Smok	Nysa	Opoka	Boruta	Arobase	Pioneer PR39G12	Eurostar	Pioneer PR39H84	Moncada		
Lys	72.4^{a}	75.4^{ab}	75.4^{ab}	84.0^{b}	74.3^{ab}	67.2^{ac}	64.3^{ac}	74.4^{ab}	60.3^{c}	72.0	7.06
Met	93.3^{b}	89.0^{ab}	91.4^{b}	92.0^{b}	88.7^{ab}	84.8^{a}	83.7^{a}	84.4^{a}	83.7^{a}	87.9	3.84
Cys	87.3^{d}	83.7^{bcd}	84.5^{bcd}	86.0^{cd}	80.7^{abcd}	71.8^{a}	76.9^{abc}	76.2^{ab}	73.4^{a}	80.1	5.69
Thr	81.2^{abc}	80.1^{abc}	81.8^{ab}	86.1^{b}	81.5^{ab}	74.3^{cde}	72.8^{de}	78.2^{ac}	68.2^{d}	78.2	5.53
Arg	86.1^{ab}	86.7^{ab}	86.8^{ab}	92.1^{b}	85.4^{a}	84.7^{a}	81.4^{ac}	85.2^{a}	77.6^{c}	85.1	3.96
His	88.2^{ab}	87.7^{ab}	89.3^{ab}	91.0^{b}	87.4^{ab}	87.8^{ab}	85.9^{ad}	83.0^{cd}	79.3^{c}	86.6	3.50
Ile	86.9^{a}	84.4^{ac}	89.1^{a}	89.2^{a}	83.2^{abc}	77.1^{bd}	78.1^{bcd}	82.5^{abc}	72.4^{d}	82.6	5.73
Leu	94.1^{a}	93.0^{ab}	94.2^{a}	94.3^{a}	92.4^{ab}	90.4^{bd}	88.3^{cd}	90.5^{bd}	85.1^{d}	91.4	3.11
Phe	91.9^{ab}	90.4^{ab}	92.1^{ab}	92.7^{b}	89.3^{ab}	87.7^{ac}	83.8^{cd}	87.5^{ac}	80.8^{d}	88.5	4.01
Val	85.6^{a}	83.2^{ab}	87.3^{a}	88.5^{a}	83.2^{ab}	77.0^{bc}	78.9^{b}	82.2^{ab}	71.7^{c}	82.0	5.34
Tyr	91.5^{ab}	90.5^{ab}	89.7^{abc}	92.2^{b}	87.6^{abcd}	86.6^{acd}	84.4^{cd}	88.5^{abc}	82.8^{d}	88.2	3.18
Ala	91.7^{a}	88.9^{a}	91.4^{a}	91.8^{a}	89.9^{ab}	86.4^{bc}	84.1^{cd}	87.4^{abc}	80.9^{d}	88.0	3.75
Asp	85.1^{a}	83.4^{ac}	85.7^{a}	89.7^{a}	85.5^{a}	76.9^{bc}	75.3^{b}	82.8^{ac}	73.8^{b}	82.0	5.41
Glu	90.3^{a}	85.8^{a}	87.5^{ab}	91.8^{a}	88.9^{ab}	90.3^{a}	88.6^{ab}	87.3^{ab}	82.4^{b}	88.1	2.82
Gly	61.5^{abc}	57.4^{abcd}	63.2^{bc}	73.7^{c}	61.1^{abc}	45.4^{ade}	42.5^{de}	56.4^{abd}	34.8^{e}	55.1	12.1
Pro	89.6^{a}	91.6^{a}	91.7^{a}	91.6^{a}	89.3^{a}	80.4^{b}	86.9^{a}	87.9^{a}	78.0^{b}	87.4	4.99
Ser	88.0^{ab}	86.6^{ab}	88.2^{ab}	90.3^{b}	87.6^{ab}	83.8^{ac}	79.4^{cd}	85.0^{abc}	76.8^{d}	85.1	4.42

$^{a, b, c}$ - means in rows with different letters differ significantly at $P<0.05$

Table 6. Correlation coefficients between content of nutrients and fibre fractions in maize grain, apparent total tract digestibility of nutrients and AME_N value

Indices	Crude fibre	ADF	ADL	NDF	IDF[1]	SDF[1]	DOM	DCP	DCF	DStarch	AME_N
Crude protein	0.05	0.28	-0.04	0.28	-0.18	-0.06	-0.01	-0.49*	0.36	0.52	0.03
Crude fat	-0.13	0.26	0.25	-0.08	-0.37	-0.05	0.07	-0.29	0.94*	0.14	0.35
Starch	0.14	-0.26	0.11	-0.25	0.08	0.15	0.12	0.48*	-0.43	-0.39	0.13
Sugars	0.33	-0.01	-0.03	0.07	-0.47*	0.07	0.40*	0.24	0.43*	0.23	0.44*
ATTD OM	0.01	-0.08	0.22	-0.14	-0.61*	0.29	x				
ATTD CP	0.01	-0.25	0.06	-0.12	-0.29	0.24	0.73*	x			
ATTD CF	-0.12	0.21	0.26	-0.09	-0.56*	-0.02	0.31	-0.12	x		
ATTD starch	0.44*	0.46*	0.05	0.58*	0.01	0.50*	0.36	0.06	0.23	x	
AME_N	0.09	0.12	0.22	0.07	-0.69*	0.39*	0.86*	0.44*	0.57*	0.52*	x

ATTD - apparent total tract digestibility: OM - organic matter; CP - crude protein; CF - crude fat; * $P<0.05$; DOM - digestible organic matter; DCP - digestible crude protein; DCF - digestible crude fibre; [1] see Table 1

DISCUSSION

Maize grain is relatively low in crude protein, but high in crude fat and metabolizable energy value for broiler chickens (AME_N) in comparison with other cereals (European Table, 1989; Sauvant et al., 2004). In the grain of the nine maize cvs used in our experiment, the average crude protein content was higher than that reported by Moore et al. (2008) and similar to the average values reported by Korniewicz et al. (2000). The nutritive value of maize protein varies according to cultivar, type of grain (dent, flint, dent/flint), growing conditions (Korniewicz et al., 2000), grain drying temperature (Kaczmarek et al., 2007), starch structure (Svihus et al., 2005), and presence of antinutrients, primarily, phytate, enzyme inhibitors, and resistant starch (Cowieson, 2005).

Crude fat content affects the content of gross energy (GE) and the metabolizable energy (AME_N) value in maize grain. The average proportion of fat in maize cultivars evaluated in our study was lower than reported by Korniewicz et al. (2000), whereas similar as in maize grains tested by Applegate (2005) and Moore et al. (2008). Two of the cultivars evaluated in our study, Pioneer PR39H84 and Moncada, had a crude fat content much lower, however, than other cultivars. Also Song et al. (2003) reported considerable differences in crude fat content among maize cultivars. In our study, the content of oleic, linoleic and linolenic acids in maize grain fat was slightly different from that given in Sauvant et al. (2004) and European Tables (1989) - the content of linoleic acid was lower and linolenic acid higher, so the n-6/n-3 FA proportion averaged 34 (Table 3). It is well known that the fatty acid composition of a diet affects the fatty acid profile in broiler meat, so fat used as a supplement of feed mixtures based on maize should contain a considerable proportion of n-3 FA.

Starch constitutes approximately 700 g/kg DM of maize grain (Bach Knudsen, 1997; Korniewicz et al., 2000). In the present study the cultivars with the highest starch content (about 75% DM) also had the lowest CP content. Interestingly, there was a significant negative correlation between starch and sugar content ($r=0.59$; $P<0.05$). Both the starch content and the proportion of amylose to amylopectins in starch are variable in maize. In the maize cultivars used in our study, the proportion of amylose in starch was 30.5%, which corresponds to the values reported for normal amylose maize (Tester et al., 2004).

Compared with other cereal species, maize grain contains less crude fibre, non-starch polysaccharides (NSP), and non-cellulose polysaccharides (NCP) (Cowieson, 2005). Bach Knudsen (1997) reported that total dietary fibre (TDF) consists of about 108 g/kg of DM, similarly as in our study. The arabinoxylans and β-glucans found in dietary fibre of some cereals absorb water to form hydrogels, which increase the viscosity of small intestinal digesta. This can reduce the activity of digestive enzymes and the absorption of nutrients. Compared with other cereal species, maize grain contains a low proportion of the insoluble fraction in total non-starch polysaccharides and considerably lower amounts of β-glucan, and these substances have no adverse effect on the extent of the digestion of maize nutrients in birds (Cowieson, 2005).

In the analysed maize grain, the average crude fibre content was lower than that given by Sauvant et al. (2004), while the content of acid- and neutral- detergent fibre varied among cultivars, similarly as in the study by Moore et al. (2008).

It is assumed that maize nutrients are generally characterized by high digestibility in broilers (European Table, 1989; Zanella et al., 1999). The results of our study indicate that some cultivars of maize can differ in the extent of nutrient digestion and in energy value. In our study, DM and OM digestibilities were similar, but crude fat digestibility was lower compared with the results obtained by Kaczmarek et al. (2007) and given in the European Table (1989). In our study, the lower coefficients of apparent crude fat digestibility were obtained for cultivars with a very low crude fat content (Pioneer PR39H84 and Moncada). Due to this, the correlation between crude fat content and coefficient of fat digestibility was - 0.94 ($P<0.01$). Lipids are present in maize grain in the outer skin, a great part as indigestible waxes, and in germ and endosperm, mainly as triglycerides and phospholipids (Cowieson, 2005). It can be assumed that in grain of both low-fat cultivars used in the present study, the distribution of crude fat between the outer skin, germ and endosperm favoured the outer skin, which makes crude fat less digestible by birds. A similar low digestibility of fat in broilers fed diets containing more than 50% maize grain was reported by Batal and Parsons (2002), who showed a significant effect of broiler age on the digestibility of fat.

In our study, the apparent coefficients of amino acid digestibility were positively correlated with crude protein content in maize grain (r from 0.40 for lysine to 0.75 for methionine) but there were, on average, about 4% lower than reported by Song et al. (2003). The coefficients of essential amino acid digestibility were negatively correlated with the TDF and IDF content in grain.

Generally, maize grain has a lower content of non-starch polysaccharides (NSP) than the other cereal grains, and the physicochemical characteristics of NSP are different. The results of our study confirm that the ratio of SDF in total dietary fibre is low and that maize SDF has no viscous or anitinutritional properties, as the jejunal digesta viscosity in chickens fed with maize ranged between 1.71 to 1.90 and was affected by neither amino acid digestibility nor AME_N values. Nonetheless, the significant negative correlation between IDF, amino acid digestibility, and AME_N values suggest the antinutritional potency of the maize IDF fraction, possibly by a cage effect. Due to supplementation of the maize-based diets with different enzymes (xylanase, α-galactosidase, β-mannanase, pectinase, α-amylase), an improvement of broiler performance was reported (Gracia et al. 2003; Cowieson, 2005). It can be attributed to release of the cage effect as well as to increased degradation of the cell walls and greater utilization of hexoses and pentoses from the small intestine.

The energy value of maize grain for broilers due to a higher content of crude fat and starch is greater compared with other cereals. In the present experiment, the AME_N value of maize cultivars was similar to that determined in maize grain by Applegate (2005). The energy value of the analysed maize cultivars was positively correlated with sugar content ($r=0.51$; $P<0.05$) and negatively with the TDF and IDF contents in grain ($r = -0.60$ and -0.69, respectively; $P<0.05$).

In the present experiment, maize cultivar had no effect on the viscosity of jejunal digesta, but was found to have a significant effect on digesta pH. A slightly lower viscosity compared with our study was reported by Maisonnier et al. (2001) for small intestinal digesta of broilers fed maize. In other studies, a slightly higher viscosity of jejunal digesta of 21-day-old broilers receiving a diet with about 60% maize grain was reported (Gonzàlez-Alvarado et al., 2007). A similar pH level to that in our study was determined in 22-day-old broiler chickens receiving a diet with about 50% maize grain by Gracia et al. (2003), while almost twice lower values were obtained by Gonzàlez-Alvarado et al. (2007). The results of our study showed that differences in the composition of maize cultivars had no influence on the development of the gastrointestinal tract.

CONCLUSIONS

In summary, the basic chemical composition, the contents of gross energy, amino acids, and fibre, as well as the fatty acid profile of maize grain can differ among maize cultivars, but it has not been proved that batch-to-batch contents within a cultivar are similar. Variation in the chemical composition of maize grain had an effect on the extent of basic nutrient digestion and energy value of grain in broiler chickens. Apart from the determination of protein content for practical utilization of maize it is important to determine the insoluble fibre fraction, as it is negatively correlated with nutrient digestibility and the AME_N value of maize.

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