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Corn types with different nutritional profiles, extruded or not, on piglets (6 to 15 kg) feeding[1]

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ABSTRACT - Two experiments were carried out to determine the nutritional value and verify piglets' performance in the nursery phase fed with diets containing common corn (CC), extruded common corn (ECC), high-lysine corn (HLC), extruded high-lysine corn (EHLC), high-oil corn (HOC) and extruded high-oil corn (EHOC). In the total digestibility trial 14 barrows averaging 6.49 ± 0.16 kg initial body weight were allotted in metabolism cages, distributed in a randomized design with seven diets, six replicates, and one piglet per experimental unit. The values of digestible energy (DE), as well as metabolizable energy (ME) as-fed basis for CC, ECC, HLC, EHLC, HOC and EHOC were: 3,428 and 3,327 kcal/kg; 3,439 and 3,355 kcal/kg; 3,533 and 3,414 kcal/kg; 3,515 and 3,427 kcal/kg; 3,483 and 3,377 kcal/kg; 3,585 and 3,482 kcal/kg, respectively. In the performance experiment, 84 piglets, weaned at 21 days old, initial live weight of 6.06 ± 0.54 kg were used. Animals were allotted in a completely randomized design in a 3 × 2 factorial arrangement, using three types of corn (CC, HLC and HOC), two forms of processing (processed or not by extrusion), seven replicates and two piglets per experimental unit. Six diets containing CC, ECC, HLC, EHLC, HOC and EHOC were studied. There were no advantages in the digestibility and performance by extruding the types of corn with different nutritional profiles, for their use in commercial diets for piglets. The results of the two experiments emphasize the importance of segregating the types of corn, extruded or not, in their real chemical and energetic composition as well as the values of true digestible amino acids for the formulation of piglet diets in the nursery phase.

Key Words: bioeconomic studies, extrusion, food energy, nutritional values, performance

Introduction

Corn is widely used in animal feed as an energy source (3,930 kcal of GE/kg), due to its high content of starch (63.00%), available in an easily digestible way and of low cost. It contains about 8.00% of crude protein and 3.60% of crude fat in its composition (Rostagno et al., 2005).

The protein contained in this cereal, although significant in amount, has lower quality than other plant and animal sources, except the protein of high-lysine corn, which is a result of genetic improvement from the Opaque-2 mutant (Oliveira et al., 2004). In this material, the quantities of amino acids lysine (0.35%) and tryptophan are increased in the grain, giving a higher nutritional quality to protein (Saldivar & Rooney, 1994). Genetic improvement of corn, grains with high levels of oil, containing 6.4% of crude fat (Rostagno et al., 2005) has also been aimed, which increases the value of energy, allowing the formulation of diets with higher energetic density.

The weaning, in addition to stressing the piglets due to the environmental change and the separation from the sow, imposes a sudden change in the feeding, since the diet which consisted of breast milk is replaced by another one with ingredients coming from plants (Barbosa et al., 2007). The feed intake by the piglets in the first days post-weaning is low, so the supply of diets with ingredients of better digestibility may be necessary for an appropriate growth in this phase (Ferreira et al., 2001).

Aiming to obtain the best possible use of corn, studies have been conducted on the processing of starch. The extrusion of the corn is extremely important, aiming at the "disruption" of the granule structure, which facilitates the action of the amylase enzyme in the process of digestion and absorption in the digestive tract. The corn properly processed by heat provides better digestibility of its nutrients, especially energy (Lawrence, 1975).

This study was carried out to evaluate the use of types of corn with different nutritional profiles, processed or not by extrusion, in practical diets of piglets (6 to 15 kg) and their

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effects on the performance and possible economical return of this use.

Material and Methods

The experiments were carried out at Fazenda Experimental de Iguatemi in Universidade Estadual de Maringá - UEM (23° 21' S, 52° 04' W, 564 m), Paraná, Brazil.

Three different types of corn were used: common corn (CC) - BR1030 hybrid, which was obtained at Embrapa CNPMS; high-lysine corn (HLC) - BR473 variety, which is under development by Embrapa CNPMS and high-oil corn (HOC) - DAS766 hybrid, from the seed company DowAgroScience.

The three types of corn were ground in a 2-mm hammer mill screen. Part of the corn was set aside in order to be added to diets in this way, while the other part was submitted to the extrusion process, using a single screen extruder (Imbra 120, Imbramac Manufacturing). The cooking temperature was 118 ºC and the pressure was 1 to 2 atm. Thus, six different types of corn were used in the studies.

The chemical composition and energy value of the CC, extruded common corn (ECC), HLC, extruded high-lysine corn (EHLC), HOC and extruded high-oil corn (EHOC), as well as the chemical composition and energy value of the diets and feces were obtained in the Laboratório de Análises de Alimentos e Nutrição Animal – LANA at Universidade Estadual de Maringá. The analysis of dry matter, crude protein, ashes, calcium, total phosphorus and crude fat were performed according to the methods described by Silva & Queiroz (2002). The determination of starch in the feed and feces was according to the enzymatic method proposed by Poor et al. (1989), adapted by Pereira & Rossi (1995). The values of gross energy were determined by means of adiabatic calorimeter (Parr Instrument Co. AC720), according to the procedures described by Silva & Queiroz (2002).

The index of the quality control of the extrusion process used was the water absorption index (WAI), according to the technique proposed by Holay & Harper (1982). Forty grams of the sample were weighed, put into a 500-mL beaker, added 200 mL of hot water (60 ºC), followed by shaking for 10 seconds. After that, the sample was left to soak for three minutes and then filtered for ½ minute in a filter paper for fast filtration. The filtrated volume (V), which represents the water not absorbed, was recorded and used for the calculation according to the equation (water absorption index (%) = [(200 - V) / 40] * 100).

The total digestibility trial was carried out, using 14 crossbred piglets from commercial line, barrows, with initial body weight of 6.49 ± 0.16 kg.

Animals were individually allotted in metabolism cages type "PEKAS" in a controlled environment room. The average temperature showed minimum of 25 ºC and maximum of 28 ºC. The mean relative air humidity of the environment showed minimum of 13% and maximum of 33%.

The tested feed was common corn (CC), extruded common corn (ECC), high-lysine corn (HLC), extruded high-lysine corn (EHLC), high-oil corn (HOC) and extruded high oil corn (EHOC), which replaced 30% of the reference diet, resulting in six test diets (TD). The reference diet consisting of basal corn and soybean meal was calculated to meet the requirements indicated by the NRC (1998).

Seven diets were studied: 1 - Reference Diet (RD); 2 - RD (70%) + CC (30%); 3 - RR (70%) + ECC (30%); 4 - RD (70%) + HLC (30%); 5 - RD (70%) + EHLC (30%); 6 - RD (70%) + HOC (30%); 7 - RD (70%) + EHOC (30%).

The collections were done in three periods, the first period was of seven days for adaptation to the diets and to the cages and five-day collection of feces and urine, with a 3-day interval, followed by the second and third periods with a five-day collection. From the first to the second period and from the second to the third, treatments were redistributed in order to avoid the same animal receiving the same diet in consecutive repetitions.

Piglets received four daily meals at 7 h 30 min, 10 h 30 min, 13 h 30 min and 16 h 30 min in proportions of 38, 19, 19 and 24% of the total, respectively, according to Moreira et al. (2001), and the other procedures, such as the provision of diets, feces and urine collection, were carried out according to those described by Sakomura & Rostagno (2007).

The digestibility coefficients of dry matter (DCDM), crude protein (DCCP), organic matter (DCOM), crude fat (DCCF), starch (DCstarch), gross energy (DCGE) and the metabolization coefficient of gross energy (MCGE), of the corns with different nutritional profiles, processed or not by extrusion were calculated as Matterson et al. (1965) did, thereby obtaining the values of digestible dry matter (DDM), digestible protein (DP), digestible organic matter (DOM), digestible fat (DF), digestible starch (DS), digestible energy (DE) and metabolizable energy (ME).

The experimental design was completely randomized, with six treatments, six replicates and the experimental unit was composed of a piglet.

In order to evaluate differences between the digestibility coefficients of the CC, ECC, HLC, EHLC, HOC and EHOC, the data was submitted to analysis of variance and average test (Newman-Keuls Test, $P<0.05$), using the statistical software SAEG (UFV, 2000), in accordance with the following statistical model: $Yij = \mu + Ti + eij$ where: Yij = digestibility coefficients of treatment i, of repetition j; μ = constant associated with all observations, Ti = the effect of food type i, where i = 1, 2, 3, 4, 5, 6 (1 = CC, 2 = ECC, 3 = HLC, 4 = EHLC, 5 = HOC and 6 = EHOC) and ij = random error associated with each observation.

Once the chemical composition and energy value of CC, ECC, HLC, EHLC, HOC and EHOC were obtained, they were used in diet formulations of the performance experiment in the nursery phase (phase I: 6 to 9 kg of BW and phase II: 9 to 15 kg of BW).

The performance experiment was carried out using 84 crossbred piglets from commercial line, weaned at 21 days with initial body weight of 6.06 ± 0.54 and finishing of 9.17 ± 1.39 kg in phase 1 and initial body weight of 9.17 ± 1.39 kg and finishing of 14.97 ± 2.83 kg in phase 2. The minimum and maximum external average temperatures were 13.0 ± 3.1 ºC and 36.0 ± 2.2 ºC, respectively.

Piglets were allotted in a nursery covered with fibrocement tiles, arranged in four rooms, divided by a central corridor, each one holding ten pens. The pens (1.32 m^2) were partially slotted using plastic floor, with frontal semi-automatic feeders and nipple drinker in the back. Diets and water were supplied *ad libitum* throughout the experimental period.

Animals were distributed in a randomized design in a 3 × 2 factorial arrangement, with three types of corn (CC, HLC and HOC) and two forms of processing (processed or not by extrusion), with seven replicates and two piglets per experimental unit .

Six diets were analyzed (Table 1), containing: 1 - basal CC; 2 - basal ECC; 3 - basal HLC; 4 - basal EHLC; 5 - basal HOC; and 6 - basal EHOC. Diets had the same nutritional levels according to NRC (1998).

For the formulations of diets, the chemical composition and energy value of CC, ECC, HLC, EHLC, HOC and EHOC were used (Tables 2 and 3).

The values of total and true digestible amino acids (lysine, methionine + cystine and threonine) were estimated based on the true digestibility coefficients obtained in the experiment of ileal digestibility (Oliveira et al., 2011), adjusted based on the CP of each type of corn studied.

For the remaining ingredients, the chemical composition and energy value proposed by Rostagno et al. (2005) were used. L-lysine and DL-methionine were added in order to comply with the requirement of ideal protein in terms of digestible amino acids, as indicated by NRC (1998).

Table 1 - Ingredient, chemical and energy compositions of the experimental diets of piglets during the nursery phase (6 to 15 kg) using corn with different nutritional profile

Item	Common corn		High-lysine corn		High-oil corn	
	Non-extruded	Extruded	Non-extruded	Extruded	Non-extruded	Extruded
Common corn	53.25	53.31	-	-	-	-
High-lysine corn	-	-	59.12	59.75	-	-
High-oil corn	-	-	-	-	51.79	53.25
Soybean meal, 45%	26.83	27.07	22.69	22.10	28.78	28.46
Skim milk	10.00	10.00	10.00	10.00	10.00	10.00
Sugar	3.000	3.000	3.000	3.000	3.000	3.000
Dried whey	2.000	2.000	2.000	2.000	2.000	2.000
Soybean oil	1.900	1.612	0.040	0.000	1.426	0.279
Dicalcium phosphate	1.269	1.264	1.317	1.310	1.273	1.251
Limestone	0.697	0.699	0.690	0.711	0.672	0.698
Supplement[1]	0.500	0.500	0.500	0.500	0.500	0.500
Sodium chloride	0.400	0.400	0.400	0.400	0.400	0.400
DL-Methionine, 99%	0.054	0.049	0.119	0.106	0.086	0.082
L-Lysine HCL, 99%	0.075	0.064	0.099	0.100	0.050	0.053
BHT	0.010	0.010	0.010	0.010	0.010	0.010
Leucomycin[2]	0.015	0.015	0.015	0.015	0.015	0.015
Calculated values[3]						
ME[3], kcal/kg	3310	3310	3310	3310	3310	3310
CP[3], %	19.5	19.5	19.5	19.5	19.5	19.5
Digestible lysine[3], %	1.10	1.10	1.10	1.10	1.10	1.10
Digestible M+C[3], %	0.63	0.63	0.63	0.63	0.63	0.63
Digestible threonine[3], %	0.69	0.69	0.69	0.69	0.69	0.69
Digestible valine[3], %	1.01	1.01	1.01	1,00	1.02	1.02
Calcium[3], %	0.76	0.76	0.76	0.76	0.76	0.76
Available phosphorus[3], %	0.37	0.37	0.37	0.37	0.37	0.37
Lactose, %	6.50	6.50	6.50	6.50	6.50	6.50

[1] Vitamin and mineral mix for piglets in the nursery phase, composition per kg of the product: vit. A - 1,800,000 IU; vit. D3 - 360,000 IU; vit. E - 4,000 IU; vit. K3 - 600 mg; vit. B1 - 280 mg; vit. B2 - 800 mg; vit. B6 - 300 mg; vit. B12 - 3,600 mg; niacin - 6,000 mg; pantothenic acid - 3,200 mg; biotin - 20 mg; pholic acid - 80 mg; choline - 31 g; Fe - 20,000 mg; Cu - 50,000 mg; Co - 120 mg; Mn - 11,000 mg; Zn - 18,000 mg; Se - 60 mg; I - 200 mg; antioxidant - 20 g; vehicle Q.S.P. - 1,000 g.

[2] Growth promoter (Leucomag - leucomycin, 30%).

[3] Calculated according to the composition of the feed indicated by Rostagno et al. (2005).

Animals were weighed at the beginning and at the end of each phase (Phase 1 – from 6 to 9 kg and Phase 2 – from 9 to 15 kg) of the experiment, and the total feed intake was computed, which was calculated with the daily feed intake (DFI), daily weight gain (DWG) and feed:gain relation (FGR) of each experimental unit.

The economic analysis of the experiment (full phase – from 6 to 15 kg) was calculated by the following expression adapted by Guidoni et al. (1997):

$$\text{MPC} \leq [\text{PRP}\ (\text{Gain}_i\text{-Gain}_0) - \sum_{J \neq L\ = 1}^{N} Pj\ (\text{C}_{ji}{*}\text{FI}_i\text{-C}_{j0}{*}\text{FI}_0)]/(\text{C}_{li}{*}\text{FI}_i)$$

where: MPC = maximum price of the corn (ECC, HLC, EHLC, HOC and EHOC) so that the diet that would be used had the same economic efficiency as the reference diet (RC); PRP = price per kilo of piglet; Gain_i = average weight gain of piglets from the treatment with corn (ECC, HLC, EHLC, HOC and EHOC); Gain_0 = average weight gain of piglets from the reference treatment (RC), P_j = price of the other ingredients in each diet; Cji = percentage of the ingredient j in the diet i; FI_i = average total feed intake per animal inherent to diet i; C_{j0} = percentage of the ingredient j in the reference diet; FI_0 = average total feed intake per animal on the reference diet; C_{li} = percentage of the corn (ECC, HLC, EHLC, HOC and EHOC) in the diet i.

The prices of the inputs in the region of Maringá/Paraná (07/2008) were used to calculate the costs of the experimental diets. The price of the common corn (CC) was R$ 0.41/kg; soybean meal, R$ 0.76/kg; milk powder, R$ 10.00/kg; sugar, R$ 0.80/kg; dried whey, R$ 4.00/kg; soybean oil, R$ 2.85/kg; limestone, R$ 0.180/kg; dicalcium phosphate, R$ 2.76/kg; sodium chloride, R$ 0.34/kg; vitamin and mineral mix for piglets, R$ 8.10/kg; L-lysine, R$ 7.08/kg; DL-methionine, R$ 26.90/kg; L-threonine, R$ 9.30/kg; anti-oxidant, R$ 10.40/kg, and growth promoter, R$ 166.00/kg. The price per kg of the piglet was R$ 7.80.

The results of the different variables were submitted to analysis of variance and to the average test (Newman-Keuls Test, P<0.05). The observations were analyzed with the following statistical model: $Y_{ijk} = \mu + Ci + Pj + (CP)ij + e_{ijk}$, where, Y_{ijk} = observed value of variables for each individual *j*, receiving the processed corn i or not; μ = general constant; C_j = effect of type of corn; j = 1, 2 and 3 (1 = common corn, 2 = high-lysine corn and 3 = high-oil corn); P_j = effect of processing form j, where, j = 1 and 2 (1 = non-extruded and 2 = extruded); (CP)ij = interaction effect on corn i and the processing form j; eij = random error associated with each observation. The statistical analyses were carried out using the statistical software SAEG (UFV, 2000).

When the interaction C × P was significant, posterior analyses were conducted and the effect of each corn in each processing forms (extruded or not) and the processing forms in each corn were studied.

Results and Discussion

High-lysine corn (HLC) and extruded high-lysine corn (EHLC) showed some difference in percentages for crude protein (29.61 and 24.87%), lysine (57.74 and 50.51%) and threonine (33.62 and 27.31%) superior to CC when converted to the same dry basis, while HOC showed a percentage difference in the ether crude fat 5.59% higher if compared with CC (Table 2).

The three types of corn which were submitted to the extrusion process showed the lowest levels of CF when compared with the non-extruded ones. These variations between the extruded and non-extruded types of corn can be mainly attributed to the loss of oil that occurred during the process of extrusion (Table 2). The same reduction was observed by Moreira et al. (2001) when evaluating the pre-gelatinized corn meal (1.99% CF), which is similar to the value of 1.71%, mentioned by Rostagno et al. (2005) for pre-cooked corn.

Bertipaglia et al. (2008), when evaluating the effects of the temperature of the extrusion process (extrusion at 80 °C, 100 °C or 120 ºC) on the content of CF of the common corn, observed a reduction of 59.1% in the proportion of free lipids in common corn extruded at 100 °C and 120 ºC. The changes in the lipid fraction resulting from the extrusion may occur due to the physical activity promoted by the pressure and heat, promoting the cell wall disruption (Mendes et al., 2004), releasing the lipid within the cell and increasing free lipid fraction.

Thus, the loss of CF thatoccurred in this case may have been caused by the cell wall disruption, which caused the leaching of the free lipid fraction part through the post-extrusion manipulation (drying process, transportation and milling of the product for laboratory analysis) thereby reducing substantially the level of CF of the extruded corns.

The values for WAI of the extruded types of corn (ECC, EHLC and EHOC) were higher (Table 2) than those of non-extruded types of corn (CC, HLC and HOC), showing that they absorbed a higher volume of water, which indicates greater degree of starch gelatinization for the extruded types.

The result of the water absorption can demonstrate the efficient degree of gelatinization, with 500% as the ideal value. Under the parameters of extrusion, the ECC, EHLC and EHOC used showed a value close to the maximum of water absorption, showing that the extrusion process was efficient. These results were different from those obtained

Table 2 - Chemical, energy and amino acid compositions of corn with different nutritional profiles, processed or not by extrusion

Item	Common corn				High-lysine corn				High-oil corn			
	Non-extruded		Extruded		Non-extruded		Extruded		Non-Extruded		Extruded	
	DM[1]	AB[2]	DM[1]	AB[2]	DM[1]	AB[2]	DM[1]	AB[2]	DM[1]	AB[2]	DM[1]	AB[2]
Dry matter, %	100	88.88	100	89.51	100	87.90	100	89.76	100	86.97	100	89.92
Gross energy, kcal/kg	4413	3923	4273	3825	4458	3919	4369	3921	4517	3929	4366	3926
Crude protein (CP), %	8.66	7.70	8.54	7.64	11.23	9.87	10.82	9.71	8.46	7.36	8.43	7.58
Lysine[3], %	0.28	0.25	0.28	0.25	0.44	0.39	0.43	0.38	0.25	0.22	0.25	0.23
Methionine +cystine[3], %	0.37	0.33	0.37	0.33	0.33	0.29	0.32	0.29	0.29	0.25	0.29	0.26
Threonine[3], %	0.32	0.28	0.31	0.28	0.42	0.37	0.41	0.36	0.29	0.25	0.29	0.26
Digestible lisine[3], %	0.25	0.23	0.25	0.22	0.39	0.34	0.39	0.34	0.20	0.17	0.20	0.18
Digestible methionine + cystine[3], %	0.35	0.31	0.34	0.30	0.29	0.25	0.28	0.25	0.24	0.21	0.24	0.22
Digestible threonine[3], %	0.30	0.27	0.30	0.27	0.39	0.34	0.38	0.34	0.26	0.23	0.26	0.23
Digestible valine[3], %	0.44	0.39	0.44	0.39	0.57	0.50	0.57	0.50	0.40	0.35	0.40	0.35
Calcium, %	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.01
Total phosphorus, %	0.24	0.21	0.24	0.22	0.28	0.25	0.25	0.23	0.21	0.18	0.24	0.21
Available phosphorus[4], %	0.08	0.07	0.08	0.07	0.09	0.08	0.08	0.07	0.07	0.06	0.08	0.07
Ash, %	1.35	1.20	1.40	1.25	1.45	1.27	1.43	1.28	1.41	1.22	1.41	1.27
Organic matter, %	98.65	87.68	98.60	88.26	98.55	86.63	98.57	88.48	98.59	85.74	98.59	88.65
Crude fat, %	4.75	4.22	1.4	1.25	4.58	4.03	2.17	1.95	5.01	4.36	2.65	2.38
Starch,%	74.65	66.35	70.67	63.26	69.40	61.01	71.04	63.76	69.96	60.84	67.21	60.44
WAI[5],%	350		435		375		455		345		445	

[1] Dry matter.

[2] As-fed basis.

[3] Estimated values of total and true digestible amino acids based on the CP of each corn from the true digestibility coefficients obtained in the experiment of ileal digestibility (Oliveira et al., 2011).

[4] Value estimated from the data by Rostagno et al. (2005).

[5] Water absorption index.

by Moreira et al. (1994a) and Moreira et al. (2001) who obtained 500% when the pre-cooked corn flour and pre-gelatinized corn meal were evaluated, however Moreira et al. (1994a) when evaluating the extruded corn found a value of 317%, which is inferior to those of this experiment.

There were no differences ($P>0.05$) in the digestibility coefficients of DM, CP, OM, CF and GE and the metabolization coefficient of gross energy between the six types of corn evaluated (Table 3). However, there was difference ($P<0.05$) in the digestibility coefficient of starch, higher for the CC, ECC, EHLC and EHOC and lower for HLC and HOC, which was expected.

The improvement in the digestibility of starch can be explained by the positive effects promoted by the extrusion process, which allow the beneficial physical changes of the starch granules, causing structural disorganization, with higher solubility in water and high absorption capacity due to the gelatinization and dextrinization (Grossmann et al., 1988; Svihus et al, 2005), making the nutrients more accessible to enzymatic digestion (Otutumi et al., 2005).

The coefficient of digestibility of CP of ECC (Table 3) is close to those obtained for the pre-gelatinized corn meal (79.70%) studied by Moreira et al. (2001) and inferior (87.00%) to the value proposed by Rostagno et al. (2005) for pre-cooked corn. It was expected that during the extrusion process there would be significant improvement in the digestibility of this nutrient for the extruded corn, since the extrusion causes the cell wall disruption, releasing the complexed or enclosed protein (Mendes et al., 2004), thereby, more sensitive to the hydrolysis by proteolytic enzymes and in many cases its digestibility and utilization increase; nevertheless, this did not occur in this experiment. These responses are similar to those obtained by Scherer (2006), who found no difference in the digestibility of CP when evaluating nutritionally the canola seed, extruded or not, for piglets in the nursery phase.

Comparing the DE, the ECC, HLC, EHLC, HOC and EHOC with the CC (dry basis), HLC and HOC showed values of DE and ME superior to CC: 4.21 and 3.81; 3.77 and 3.72% respectively. HLC has better digestibility of energy and superior values of DE and ME, probably due to an increase of 37.57; 3.13; 2.56% of the value of DP, DOM and DCF, respectively. HOC had 2.69 and 14.46% higher DOM and DCF. The extruded corns did or did not have some subtle improvement in the digestibility of energy and energy values when compared with the CC, showing that there were no beneficial effects promoted by the extrusion.

Similarly, by comparing the EHLC to the HLC and the EHOC to the HOC, when converted to the same dry basis, it is also noted that the extrusion process was not effective, once there was no improvement in the digestibility of energy and energy values. Although there were benefits to the starch gelatinization during the extrusion, since the coefficients of digestibility of starch were better ($P<0.05$)

Table 3 - Apparent digestibility coefficients of metabolization coefficient and values of digestible corn with different nutritional profiles, processed or not by extrusion, studied at the nursery phase[1]

Digestibility (%)	Common corn				High-lysine corn				High-oil corn			
	Non-extruded		Extruded		Non-extruded		Extruded		Non-extruded		Extruded	
ADC of dry matter	92.10		90.25		96.66		93.32		95.76		90.87	
ADC of crude protein	79.55		79.16		84.45		84.52		76.13		77.66	
ADC of organic matter	92.21		92.82		95.18		94.96		94.75		91.06	
ADC of crude fat	82.99		76.19		87.98		81.60		89.82		84.90	
ADC of starch	99.74a		99.43a		88.69b		99.82a		85.44c		99.89a	
ADC of gross energy	87.39		89.92		90.17		89.65		88.64		91.32	
MC of gross energy	84.81		87.72		87.14		87.40		85.95		88.70	
Digestible nutrients	DM[2]	AB[3]	DM[2]	AB[3]	DM[2]	AB[3]	DM[2]	AB[3]	DM[2]	AB[3]	DM[2]	AB[3]
Digestible dry matter, %	-	72.76	-	72.31	-	74.69	-	75.18	-	72.44	-	73.46
Digestible protein, %	6.89	6.13	6.76	6.05	9.48	8.34	9.14	8.21	6.44	5.6	6.55	5.89
Digestible organic matter, %	90.96	80.85	91.52	81.92	93.80	82.46	93.60	84.01	93.41	81.24	89.78	80.73
Digestible fat, %	3.94	3.50	1.06	0.95	4.03	3.55	1.77	1.59	4.50	3.92	2.25	2.02
Digestible starch, %	74.45	66.18	70.27	62.90	61.55	54.11	70.91	63.65	59.77	51.99	67.13	60.36
Digestible energy, kcal/kg	3857	3428	3842	3439	4020	3533	3917	3515	4004	3483	3987	3585
Metabolizable energy, kcal/kg	3743	3327	3749	3355	3884	3414	3818	3427	3882	3377	3873	3482
ME:DE relation	0.97		0.98		0.97		0.98		0.97		0.97	

[1] CAD values with different letters in the same row are different (Newman-Keuls test, P<0.05).

[2] Dry matter.

[3] As-fed basis; ADC = apparent digestibility coefficients; MC = metabolization coefficient.

for the extruded corns (Table 3), the other coefficients of digestibility of DM, CP, OM and CF were similar, thus not contributing to the improvement in the energy value of the extruded corn.

Studies with the use of types of corn with different nutritional profiles extruded in the piglet feed are scarce; however, similarly to this case, Moreira et al. (1994a) noticed that the extrusion of the common corn did not improve the digestibility of GE, which remained similar to the non-extruded common corn, differing from those obtained by Herkelman et al. (1990), who found some improvement in the digestibility of extruded common corn for piglets.

By applying the value of digestible nutrients obtained in this experiment in the equations (DE (as-fed basis) = 5.65 DP + 9.45 DF + 4.14 (DOM - DP - DF) and ME (as-fed basis) = 4.95 DP + 9.45 DF + 4.14 (DOM - DP - DF) described by Rostagno et al. (2005) for foods of plant origin for pigs, we find the energy values (DE and ME) of CC, ECC, HLC, EHLC, HOC and EHOC (3626 and 3583; 3533 and 3491; 3728 and 3670; 3686 and 3629; 3656 and 3617; 3538 and 3497 kcal/kg, respectively), which are superior to those obtained (Table 3). The average ME:DE relation obtained above was 0.99, greater than the one found (0.97).).

There was interaction ($P<0.05$) between the type of corn and processing for the variable DFI (Table 4) of piglets in Phase 1 (from 6 to 9 kg). The interaction split showed that the extrusion process improved the DFI only for HLC. There was difference ($P<0.05$) of DFI between the non-extruded and extruded types of corn. For the non-extruded, CC presented DFI greater than HLC. For the extruded ones, ECC and EHLC showed DFI higher than EHOC. As there was no difference ($P>0.05$) for DWG and FGR, it can be inferred that the extrusion process did not improve the quality of the types of corn with different nutritional profiles.

Daily weight gain and feed:gain showed no interaction ($P>0.05$) between the different types of corn and processing (Table 4).

There was no interaction ($P>0.05$) between corn and processing for DFI, DWG and FCR (Tables 5 and 6) of piglets in Phase 2 (from 9 to 15 kg) and Total (from 6 to 15 kg). However, it was observed that the DFI was higher ($P<0.05$) for the extruded types (Table 5 and 6). It may be that the extrusion of different variations of corn has a better acceptability and palatability of the processed corn by the piglets in this phase. Difference was also observed for the DFI between types of corn, processed or not by extrusion (Table 6), where the CC showed higher DFI ($P<0.05$) than HOC.

In this experiment, extrusion did not improve the use of different types of corn, and it was observed that the performance of the piglets was similar in the different ages of growth.

This response is probably because the diets were isonutrient (isoenergetic, isophosphoric, isocalcic, isoaminoacidic for lysine, methionine + cystine and threonine). As for the formulation of feed, the true chemical composition and energy value was used, as well as the true digestible amino acids estimated from the different types of corn, determined in ileal digestibility assays. This has permitted to formulate a diet that complied adequately with the nutritional requirements proposed by NRC (1998), and thus, the piglets showed similar performance.

Table 4 - Performance of piglets in Phase 1 (from 6 to 9 kg) fed with diets containing corn with different nutritional profiles, processed or not by extrusion

Processing	Common corn	High-lysine corn	High-oil corn	Average[1]
	Daily feed intake, kg			
Non-extruded	0.377A	0.327bB	0.342AB	0.349 ± 0.008
Extruded	0.392A	0.373aAB	0.318C	0.361 ± 0.011
Mean[1]	0.384 ± 0.012	0.350 ± 0.010	0.330 ± 0.010	0.355 ± 0.001
	Daily weight gain, kg			
Non-extruded	0.217	0.183	0.190	0.197 ± 0.008
Extruded	0.212	0.209	0.172	0.198 ± 0.007
Mean[1]	0.215 ± 0.010	0.196 ± 0.008	0.181 ± 0.008	0.197 ± 0.001
	Feed:gain			
Non-extruded	1.79	1.84	1.83	1.82 ± 0.068
Extruded	1.89	1.81	1.87	1.85 ± 0.047
Mean[1]	1.84 ± 0.085	1.82 ± 0.063	1.85 ± 0.068	1.84 ± 0.035

[1] Mean ± standard error.

Means followed by different letters (uppercase in the row and lowercase in the column) differ (P<0.05) by Newman-Keuls test.

Table 5 - Performance of piglets in Phase 2 (from 9 to 15 kg) fed with diets containing corn with different nutritional profiles, processed or not by extrusion

Processing	Common corn	High-lysine corn	High-oil corn	Average[1]
	Daily feed intake, kg			
Non-extruded	0.787	0.660	0.642	0.698 ± 0.033b
Extruded	0.795	0.808	0.750	0.781 ± 0.016a
Mean[1]	0.787 ± 0.026	0.730 ± 0.042	0.698 ± 0.029	0.740 ± 0.013
	Daily weight gain, kg			
Non-extruded	0.462	0.369	0.383	0.405 ± 0.022
Extruded	0.431	0.432	0.437	0.433 ± 0.016
Mean[1]	0.446 ± 0.019	0.400 ± 0.029	0.411 ± 0.020	0.419 ± 0.009
	Feed:gain			
Non-extruded	1.72	1.88	1.68	1.76 ± 0.071
Extruded	1.87	1.91	1.76	1.85 ± 0.067
Mean[1]	1.79 ± 0.065	1.89 ± 0.098	1.72 ± 0.087	1.80 ± 0.025

[1] Mean ± standard error.

Means in the columns followed by different lowercase letters are different (P<0.05).

Table 6 - Performance of piglets in Total Phase (from 6 to 15 kg) fed with diets containing corn with different nutritional profiles, processed or not by extrusion

Processing	Common corn	High-lysine corn	High-oil corn	Average[1]
	Daily feed intake, kg			
Non-extruded	0.544	0.467	0.454	0.488 ± 0.019b
Extruded	0.558	0.562	0.508	0.543 ± 0.012a
Mean[1]	0.551 ± 0.018B	0.515 ± 0.023AB	0.481 ± 0.017A	0.516 ± 0.010
	Daily weight gain, kg			
Non-extruded	0.315	0.251	0.255	0.274 ± 0.015
Extruded	0.295	0.307	0.288	0.297 ± 0.010
Mean[1]	0.305 ± 0.014	0.279 ± 0.018	0.272 ± 0.015	0.285 ± 0.008
	Feed:gain relation			
Non-extruded	1.76	1.92	1.82	1.83 ± 0.058
Extruded	1.91	1.86	1.80	1.86 ± 0.051
Mean[1]	1.84 ± 0.065	1.89 ± 0.063	1.81 ± 0.072	1.85 ± 0.028

[1] Mean ± standard error.

Means in columns followed by different lowercase letters are different (P<0.05).

Means in rows followed by different uppercase letters are different (P<0.05).

O'Quinn et al. (2000) found no difference in the performance of piglets weaned and fed with diets with total substitution of common corn by high-protein and high-oil corn in conventional pig diets. However, Adeola & Bajjalieh (1997), studying high-oil corn in total substitution of common corn in diets of piglets of 25 kg of body weight, observed an improvement of 8% to 10% in feed efficiency.

The results of this experiment are consistent with Moreira et al. (1994b), Barbosa et al. (1999), Hongtrakul et al. (1998) and White et al. (2005), who did not observe improvement in the performance using processed corn in comparison with common corn, by using piglets weaned at 21 or 28 days of life. According to Moreira et al. (1994b), this is due to the high wastage of feed, because the particle size of pre-cooked corn is very fine, although the particle size has not been a problem observed in this experiment.

Other studies reported positive responses to the performance for extrusion (Fadel et al., 1988, Sayre et al., 1988). A possible explanation for the different responses to extrusion may be: type of extruder (humid vs dry) and (or) conditions of the extruder (e.g., humidity, temperature and pressure).

Using the data of weight gain and feed intake for each type of corn, equations 1, 2, 3, 4 and 5 were developed relating to the use of ECC, HLC, EHLC, HOC and EHOC in the diets of piglets in the total nursery phase (from 6 to 15 kg), respectively, in order to estimate the maximum price of ECC, HLC, EHLC, HOC and EHOC to be paid, so that it is economically viable when compared with the CC (reference corn).

Equation 1, maximum price of ECC in diets for piglets in the total nursery phase (from 6 to 15 kg): $MPECC \leq -0.04574 \times PRP + 0.00699 \times PSM + 0.00093 \times PM + 0.00028 \times PS + 0.00019 \times PDW - 0.00523 \times PSO + 0.000102 \times PL + 0.000002 \times PDP + 0.000004 \times PSA + 0.000005 \times PMX - 0.0002 \times PLI - 0.000009 \times PM + 0.00000009 \times PAN + 0.00000014 \times PGP$.

Equation 2, maximum price of HLC in diets for piglets in the total nursery phase (from 6 to 15 kg): $MPHLC \leq -0.11721 \times PRL - 0.14464 \times PSM - 0.02781 \times PM - 0.00834 \times PS - 0.00556 \times PDW - 0.03674 \times PSO - 0.00206 \times PL - 0.00272 \times PDP - 0.00111 \times PSA - 0.00139 \times PMX + 0.000197 \times PLI + 0.000949 \times PM - 0.000003 \times PAN - 0.000004 \times PGP$.

Equation 3, maximum price of EHLC in diets for piglets in the total nursery phase (from 6 to 15 kg): $MPEHLC \leq -0.01037 \times PRP - 0.06349 \times PSM + 0.005874 \times PM + 0.001753 \times PS + 0.001169 \times PDW - 0.03069 \times PSO + 0.000642 \times PL + 0.001428 \times PDP + 0.000234 \times PSA + 0.000292 \times PMX + 0.000462 \times PLI + 0.000902 \times PM + 0.0000006 \times PAN + 0.0000009 \times PGP$.

Equation 4, maximum price of HOC in diets for piglets in the total nursery phase (from 6 to 15 kg): $MPHOC \leq -0.13973 \times PRP - 0.07427 \times PSM - 0.04171 \times PM - 0.01251 \times PS - 0.00834 \times PDW - 0.01708 \times PSO - 0.00339 \times PL - 0.00522 \times PDP - 0.00167 \times PSA - 0.00209 \times PMX - 0.0008 \times PLI + 0.000393 \times PM - 0.0000042 \times PAN - 0.0000063 \times PGP$.

Equation 5, maximum price of EHOC in diets for piglets in the total nursery phase (from 6 to 15 kg): $MPEHOC \leq -0.05117 \times PRP - 0.00647 \times PSM - 0.01382 \times PM - 0.00415 \times PS - 0.00276 \times PDW - 0.03307 \times PSO - 0.00094 \times PL - 0.00209 \times PDP - 0.00055 \times PSA - 0.00069 \times PMX - 0.00052 \times PLI + 0.000451 \times PM - 0.0000014 \times PAN - 0.0000021 \times PGP$.

where: MP is the maximum price of ECC, HLC, EHLC, HOC or EHOC to have the same economic efficiency as the reference diet (CC); PRP, price of the kg of live piglet; PSM, price of the kg of soybean meal; PM, price of the kg of skim milk; PS, kg price of the sugar; PDW, price of the kg of dried whey; PSO, price of the kg of soybean oil; PL, price of the kg of limestone; PDP, price of the kg of dicalcium phosphate; PSA, price of the kg of salt; PMX, price of the kg of vitamin and mineral mix for piglets; PLI, price of the kg of L-lysine; PM, price of the kg of DL-methionine; PAN, price of the kg of the antioxidant and PGP, price of the growth promoter.

Applying the equations and the prices prevailing during the period of the experiment, we can obtain the maximum prices of the corns so that the experimental diets have the same economic efficiency of the diet with the reference corn (CC), at total nursery phase (from 6 to 15 kg). The bioeconomic studies indicated that ECC, HLC, EHLC, HOC and EHOC were not economically viable to substitute CC.

Conclusions

Extrusion did not improve the digestibility coefficients of energy, or the energy metabolization coefficient of the types of corn with different nutrient profiles. The values of digestible energy and metabolizable energy (as-fed basis) for common corn, extruded common corn, high-lysine corn, extruded high-lysine corn, high-oil corn and extruded high-oil corn are 3,428 and 3,327; 3,439 and 3,355; 3,533 and 3,414; 3,515 and 3,427; 3,483 and 3,377; 3,585 and 3,482 kcal/kg, respectively. There are no advantages in terms of digestibility and performance in extruding corn with different nutritional profile for using in feed for piglets with 6 to 15 kg of body weight. Segregating corns were economically unfeasible to substitute the common corn.

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