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Site and extent of amino acid digestion in dairy cattle fed with corn and its byproducts

Local e extensão da digestão de aminoácidos em bovinos leiteiros alimentados com milho e seus subprodutos

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Abstract

The study was conducted to evaluated the site and extent of dry matter (DM), crude protein (CP), methionine (Met), lysine (Lys), and threonine (Thr) digestion of corn and byproducts obtained from corn germ mixed with different amounts of extruded or non-extruded ether extract (EE) in dairy cattle. Treatments consisted in eight types of feed and two processing in a 4 × 2 factorial design. There were four feeds: corn grain cracked (Corn), corn germ meal with 1% EE (CG1), corn germ meal with 7% EE (CG7), and corn germ meal with 10% EE (CG10). The feeds were processed in one of two ways: extruded (Ex) and not extruded. In situ techniques were used to determine DM, CP, Met, Lys, and Thr partial and total tract digestion. A basic diet was compounded of corn germ meal, soybean meal and coastcross hay in a 70:30 roughage to concentrate ratio. There was no interaction ($P>0.05$) between feeds and processing method. Extrusion improved ($P<0.05$) total tract digestibility of corn DM but not CP. Intestinal digestibility was similar ($P>0.05$) for corn and corn germ meal mixed with 7 and 10% EE, regardless of EE processing method. The CP total tract digestibility of corn germ meal with 1% non-extruded EE was 16.62% higher ($P<0.05$) than that of the extruded form. The best total CP digestibility was obtained for corn germ meal with 7% EE, independently of the processing method. The effects of EE processing method on partial and total digestibility differed between amino acid. Corn and corn byproduct extrusion may improve dry matter digestibility, but do not necessarily influence crude protein digestion. Ruminal and intestinal digestibility of Met, Lys, and Thr depends on both feed type and processing method. Therefore, amino acid availability should be considered individually.
Key words: Extrusion, germ meal, lysine, methionine, rumen

Resumo

O estudo foi realizado para avaliar o local e a extensão da digestão da matéria seca (MS), proteína bruta (PB), metionina (Met), lisina (Lys) e treonina (Thr) em milho e seus derivados obtidos a partir

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do gérmen de milho, com diferentes quantidades de extrato etéreo (EE), extrusados ou não, oferecidos para gado leiteiro. Os tratamentos consistiram em oito tipos de alimentos, em arranjo fatorial 4 x 2: quatro dietas (grão de milho moído (Milho); farelo de gérmen de milho com 1% de EE (CG1); farelo de gérmen de milho com 7% de EE (CG7); farelo de gérmen de milho com 10% de EE (CG10)), e dois processamentos extrusado (Ex) e não extrusado. Utilizou-se a técnica *in situ* para obter a digestão total e parcial no trato da MS, PB, Met, Lys e Thr. A ração básica foi composta de farelo de gérmen de milho, farelo de soja e feno de coastcross numa relação volumoso:concentrado de 70%:30%. Não houve interação (P>0,05) entre dieta e processamento. A extrusão melhorou a digestibilidade total da MS do milho, mas não para a PB. A digestibilidade intestinal foi similar (P>0,05) entre milho e farelo de gérmen de milho com 7 e 10% de EE, independente da extrusão ou não. Sem extrusão, a digestibilidade total da PB do farelo de gérmen de milho com 1% de EE foi 16,62% maior (P<0,05), em relação a forma extrusada. A melhor digestibilidade total da PB foi obtida para farelo de germen de milho com 7% de EE, independentemente do processo. Efeitos sobre parcial ou digestibilidade total depende do aminoácido. Concluiu-se que o milho e subprodutos da extrusão poderia melhorar a digestibilidade da MS, mas não influencia necessariamente a PB. A digestibilidade ruminal e intestinal da Met, Lys e Thr depende da dieta e processamento. Portanto, a disponibilidade de aminoácidos deve ser considerada individualmente.

Palavras-chave: Extrusão, farelo de gérmen, lisina, metionina, rúmen

Introduction

The amino acid (AA) requirements for lactating dairy cows deserves special attention because deficiencies could severally impact production. Lysine (Lys) and methionine (Met) are recognized as first-limiting amino acids (PISULEWSKI et al., 1996; SCHWAB, 1992; NRC, 1996), and deficiencies can result in failure to increase milk yield, low protein yield, and low protein and fat content (SOCHA et al., 2005; WEEKES; LUIMES; CANT, 2006).

The first challenge related to the AA supply for ruminants is the selection of ingredients that, even after ruminal fermentation, provide a suitable quantity of these compounds to the duodenum. The simple addition of an ingredient rich in AA may not be enough to ensure that the AA requirements are reached because degradation in the rumen varies among feedstuffs. Therefore, the profile of the AA flowing to the duodenum can be markedly different from the absorbed fraction that originates from the undegradable rumen protein (PRESTLOKKEN; RISE, 2003; MJOUN et al., 2010).

The diets of dairy cattle are usually corn based and large amounts of Met are expected to flow to the duodenum. However, the actual amount of Met flowing into the duodenum depends on the extent of protein degradability and microbial contributions. Therefore, optimizing Met intake by manipulation of diet composition does not result in absorption of the ideal AA profile.

The use of AA protected against microbial fermentation might be a good option for ensuring absorbance of the optimal AA profile because it would allow intact AA to reach the duodenum. However, the nutritional value of any protected AA will depend on its intestinal digestibility and absorption efficiency (SOLANAS et al., 2008). In addition, this technology is expensive in many countries and may not be practical, depending on the level of cow production.

The heat treatment of cereal grains may decrease microbial activity and preserve AA from rumen degradability. The extrusion enhances intestinal digestibility, but the effect of extrusion on the extent of rumen degradation depends upon the cereal grain (LUND; WEISBJERG; HVELPLUND, 2008; SOLANAS et al., 2008). As dairy diets are often corn based and provide significant amounts of Met, it is very important to study corn processing and its effect on digestion. Many byproducts from corn that have nutritional qualities are created by

industry. The incorporation of these byproducts into cattle diets could decrease costs without affecting animal production. Oil is extracted from corn germ by a solvent, yielding a corn byproduct that contains different amounts of fat, depending of the process. This byproduct contains a large amount of protein and, because of the Met content of corn germ, incorporation of this byproduct into feeds may provide AA and energy to dairy cattle. However, further processing the corn germ by extrusion may alter the site and extent of digestion.

The aim of this study was to evaluate the site and extent of DM, CP, Lys, Met and Thr digestion of corn and extruded and non-extruded corn germ, in cattle diets.

Material and Methods

Animals, diets, and feeding management

The experiment was carried out at the Faculdade de Ciências Agrárias e Veterinárias, Universidade Estadual Paulista "Julio de Mesquita Filho," Jaboticabal, São Paulo, Brazil. Three ¾ Holstein × Nellore steers with an average weight of 300 kg that were canullated in the rumen, abomasum, and duodenum were used. Animals were housed in individual pens (8 m^2), following the guidelines for animal protection used for experiments in the European Economic Community (EC Directive 86/609/EEC). Each experimental period (three periods) lasted 17 d, with 10 d for adaptation and 7 d for sampling. The steers received the same diet at the same time.

The corn byproducts were obtained after starch and oil extraction, resulting in feeds containing 1%, 7%, or 10% lipids. In half of the feeds, the corn and corn byproducts were extruded. Thus, treatments consisted of eight types of feeds, in a 4 × 2 factorial design. There were four feeds: corn grain cracked (Corn), corn germ meal with 1% EE (CG1), corn germ meal with 7% EE (CG7), and corn germ meal with 10% EE (CG10). The feeds were processed in one of two ways: extruded (Ex) and not extruded. The extrusion temperature was 100 °C, with a matrix of 3.5 mm and 25% of initial moisture.

Steers fed *ad libitum* and the feed was replenished twice each day at 8:00 and 17:00 hours, according to NRC (2001) recommendations. Feeds contained 70% coastcross hay (*Cynodon dactylon* L. Pers), and 30% concentrate with 22.2% corn germ meal 7% lipids, 7.2% soybean meal, and 0.6% mineral premix. The chemical compositions of feed ingredients are shown in Table 1, and the amino acid compositions of feeds are shown in Table 2.

Table 1. Bromatological composition of feedstuffs and diet fed to cannulated steers.

Component[1]	Corn	Germ 1%	Germ 7%	Germ 10%	Diet
DM (%)	89.2	82.6	88.5	90.4	88.3
CP (%DM)	10.8	15.4	14.9	11.4	9.4
EE (%DM)	3.0	1.0	8.4	10.1	2.5
CF (%DM)	6.7	6.0	5.3	13.8	33.9
Ash (%DM)	1.5	4.6	2.6	5.3	5.7

DM = dry matter; CP = crude protein; EE = ether extract; CF = crude fiber.
Source: Elaboration of the authors.

Experiments of *in situ* and intestinal digestibility were determined using a mobile bag technique. Total digestibility of DM, CP, Met, Lys, and Thr were measured. The *in situ* degradability of each food (corn and defatted germ with 1%, 7%, or 10% ether extract, extruded or non-extruded), was determined

after 12 hours of ruminal incubation. For this degradation study, three bags for each ingredient were inserted into each steer. Approximately 5 grams of feed ingredient, representing approximately 22 mg DM/ cm² was placed into nylon bags (polyamide 10%) with no resin that measured 15.0 × 7.5 cm and had a porosity of 40 microns. After removal from the rumen, the bags were cooled in ice water to stop microbial activity and washed in cold water. The bags were then dried in an oven with forced ventilation at 55°C for 24 hours. After drying, the bags were weighed and analyzed to determine their DM, nitrogen (AOAC, 1995), and AA (MOORE; SPACKMAN; STEIN, 1958) content.

Table 2. Amino acid composition of corn and corn byproducts used in the experimental diet (mg% dry defatted).

Amino Acids	Corn	1% Germ	7% Germ	10% Germ
Lysine	0.5	0.6	0.5	0.4
Histidine	0.4	0.4	0.3	0.3
Arginine	0.8	0.9	0.7	0.7
Aspartic acid	0.9	1.3	0.9	0.9
Threonine	0.4	0.6	0.4	0.4
Serine	0.5	0.7	0.6	0.6
Glutamic acid	1.5	2.3	1.6	1.9
Proline	0.8	0.9	0.6	0.9
Glycine	0.5	0.8	0.6	0.5
Alanine	0.7	1.0	0.7	0.9
Cystine	0.2	0.2	0.2	0.1
Valine	0.4	0.5	0.4	0.4
Methionine	0.2	0.3	0.2	0.2
Isoleucine	0.2	0.4	0.3	0.3
Leucine	0.7	1.1	0.9	1.0
Tyrosine	0.3	0.4	0.3	0.4
Phenylalanine	0.4	0.6	0.4	0.5

Source: Elaboration of the authors.

The waste not degraded in the rumen were washed with cold water and dried. Posteriorly aliquot of the residue was removed for study of post-ruminal digestion. To study post-ruminal digestion, one gram of each feed ingredient residue was placed in 3.0 × 5.0-cm bags made of the same nylon described above. The bags were heat-sealed and incubated for 1 hour in the abomasum. After removal from the abomasum, the bags were inserted into the type T duodenal cannula, of the same animal. During the experimental period, 10 bags (for each feed ingredient) were inserted into each steer at 5-minute intervals using the method described by TEIXEIRA et al. (1988).

The bags were collected in the feces within 14 hours. The bags were washed with cold water and placed in a drying oven at a regulated temperature of 55°C for 24 hours. The dry bags were weighed and the DM, nitrogen, and AA content of the residue were determined using the same methods as for ruminal residues.

Amino acid analysis was performed using digestion by acid hydrolysis followed by HPLC reverse phase chromatography. The analyses were performed at the Laboratory of Protein Chemistry,

Faculty of Medicine, USP, Ribeirão Preto-SP. Aliquots of 5 to 10 mg degreased residue, were weighed into 10 × 150-mm borosilicate and pyrolyzed at 400°C for 8 hours. To each vial, was added 0.500 mL of 6 mol/L hydrochloric acid solution (redistilled at 104°C) containing 0.1% phenol (w/v). Each vial was placed in a digester block at 110°C for 22 hours, according to Moore, Spackman and Stein (1958).

Samples were introduced into the HPLC by adding 0.010 - 0.900 of digested sample to a cation exchange column and eluted by the analyzer difference in pH and ionic strength (SPACKMAN et al., 1963). After chromatographic separation, AA eluted from the column were reacted with ninhydrin at a temperature of 100°C for 15 minutes and the products of this reaction were detected colorimetrically at two wavelengths: 440 nm and 570 nm.

Identification of peaks was performed on the basis of the retention times of each amino acid. The HPLC was calibrated with standard amino acid solution containing 5.0 nmols of each residue injected. The peak height was used to obtain the factor calculated and each peak was assumed to have a Gaussian shape. These measurements were performed manually (ALONZO; HIRS, 1968) and the base and height of each peak were determined using a sheet designed in the laboratory. The device was optimized to operate in a linear range 1.0-10.0 nmols and the calculation of each AA concentration was based on the total height of the peaks.

The experiment had a randomized-block design with a 4 × 2 factorial scheme, where each animal was a block and the factors included four types of feed and 2 processing methods (extruded or non-extruded). The regression analyses between means and F tests were performed using the statistical package R (2005). Data were analyzed using the following model:

$$Yijl = \mu + Ai + Ej\ (i) + SSO\ (ji).\ Xji + SSL\ (ji).\ X^2 + ji + Bk\ \epsilon_{ijk}$$

Where:

Yijl = i feed type, j extrusion, block k

Xji = Linear interaction of feed and extruded j

μ = Average

Ai = Effect of Feed

SSO (ji) = Linear effect of fat (Xji) into i (germ) extruded j.

SSL (ji) = Quadratic effect of fat (Xji) into i (germ) extruded j.

Ej (t) = Effect of food within the extrusion j i

B = Effect of block

ϵ_{ijk} = Experimental error

Results and Discussion

The ruminal, intestinal, and total digestibility of DM and crude protein contained in corn and corn germ can be found in Table 3. Regardless of the food, extrusion increased ruminal digestion of DM ($P<0.05$). However, extrusion increased total DM digestion for corn germ and containing 1% EE.

Crocker et al. (1998) found no significant effect of the treatment of corn with hot steam for 30 minutes at 30°C. The total DM digestibility reported by Crocker et al. (1998) ranged from 68.1% to 71.0% and is in agreement with those obtained in the present study. Knowlton, Glenn and Erdman (1998) found no differences ($P>0.05$) between the total DM digestibility of diets containing ground corn (62.0%) and rolled corn (58.9%).

Table 3. Ruminal, intestinal, and total digestibility (%) of dry matter and total crude protein digestibility of extruded and non-extruded corn and corn-germ meal.

	Feed				CV (%)
	Corn	1% Germ	7% Germ	10% Germ	
	Ruminal digestibility of dry matter				
Without extrusion	37.5 Bb	56.7 Ba	56.8 Ba	55.1 Ba	
With extrusion	52.3Ac	69.0 Aa	68.9 Aa	61.6 Ab	2.9
	Intestinal digestibility of dry matter				
Without extrusion	38.8a	28.6b	41.1a	35.7a	
With extrusion	40.0a	17.1b	32.9a	33.2a	13.1
	Total digestibility of dry matter				
Without extrusion	61.8Bb	69.2Bab	74.7Aa	71.3Aa	
With extrusion	71.5Ab	75.2Aab	79.2Aa	74.5Aab	3,1
	Total of digestibility of crude protein				
Without extrusion	68.6 Ab	80.0 Aa	83.9 Aa	75.5 Aab	
With extrusion	74.2 Aab	68.6 Bb	80.2Aa	77.8 Aab	4,7

Means followed by the same small letter in rows, and capital letters in columns, are different (Tukey test; $P > 0.05$).
Source: Elaboration of the authors.

Boer, Murphy and Kennely (1987) demonstrated the effect of flow kinetics on total feed digestibility. When incubated in nylon bags in the rumen, corn byproducts observed for 8 hours had a ruminal DM of 22.4% and an intestinal digestion of 72.8% for a total DM digestion of 95.2%. When the ruminal incubation time was increased to 24 hours, ruminal degradation increased to 30.1% and intestinal digestion decreased to 62.0%, resulting in total DM digestion of only 88.7%. Philippeau, Deschault of Le Monredon and Michalet-Doreau (1999) reported total DM digestibility of 66.9-75% that was not affected by the variety of corn.

The total CP digestibility feeds are shown in Table 3. Following the behavior of the DM, the protein digestibility of corn germ was significantly higher than that of corn. These data indicate a change in the solubility of the zein protein in corn or variations in the relative concentration of zein and glutelin proteins.

Zein proteins are more abundant than glutelin proteins and are dispersed throughout the grain of corn (VAN BARNEVELD, 1999). Extracting the starch from corn to obtain CG1, CG7, and CG10, probably removes much of this protein and, consequently, increases the proportion of glutelin. As its name indicates, glutelin is a component of gluten and is superior to zein in terms of both the proportion of essential amino acids it contains and its digestibility and recovery.

However, maize zein may increase substantially after industrial farming practices were introduced.

Ruminal CP digestion of non-extruded corn germ was linearly related to total CP digestibility, whereas ruminal CP digestion of extruded corn germ had a quadratic relationship with total CP digestion. The effect of extrusion on the total CP digestibility of corn was not significant ($P < 0.05$). For CG1, extrusion reduced the availability of nitrogen for the metabolism of cattle. As CG1 had relatively low lipid content (Table 1), and was subjected to an extensive process in order to extract the oil, the effect of the extrusion temperature and pressure impaired CP digestion ($P < 0.05$; Table 3). Due to the differences in starch, protein, and oil in each feed, they behaved differently during extrusion.

Crocker et al. (1998) found no significant effect of 103°C steam treatment on total nitrogen

digestibility in cattle. They reported that total N digestibility of 100% corn was 69.2%. The apparent production of microbial nitrogen was 30.2 g/kg organic matter digested in the rumen. A similar value for microbial nitrogen production was reported by Knowlton, Glenn and Erdman (1998): 32.5 g/kg total OM digested. Knowlton, Glenn and Erdman (1998) also reported that the total nitrogen digestibilities of dry and treated corn were significantly different (57.5% and 65.4%, respectively). These observations were similar to those of the present study. In his review, Theurer (1986) reported an average total N digestibility for corn of 68.0%. Philippeau, Philippeau, Deschault of Le Monredon and Michalet-Doreau (1999) did not observe any significant differences in the total nitrogen digestion of extruded and non-extruded corn, with values ranging between 68.6% and 72.3%.

Total in situ digestion of Lys did not differ between foods (P>0.05) and was not affected by extrusion (P>0.05). Neither the processing required to obtain corn byproducts nor extrusion significantly affected ruminal Lys digestibility (P > 0.05). AA digestibility data are presented in Tables 4, 5, and 6. As indicated by the high ruminal digestibility and moderate intestinal digestibility, nearly all of the Lys in the foods tested was available to the animal, either in the rumen or intestine. Lys is a major component of the proteins in the corn and corn byproducts studied and the data from this study suggests that it is highly digestible. Reports in the literature indicate that the availability of Lys limits cattle performance. Our results contrast with those of Maiga, Schingoethe and Henson (1996) and Piepenbrink and Schingoethe (1998). Maiga, Schingoethe and Henson (1996) observed increased concentrations of Lys, Thr, and Met in corn gluten that was incubated for 12 hours in the rumen. The Lys content increased from 1.37% of the protein in the original material to 1.45% in the residue of incubation. Similarly, Met increased from 1.91% to 1.99% and Thr increased from 3.21% to 3.37% of the protein. Piepenbrink and Schingoethe (1998) observed that variations in Lys concentrations were 1.47% of PB for original protein supplements, corn gluten, but were 1.98% after 12 hours of ruminal incubation. Met increased from 2.15 to 2.62% CP and Thr decreased from 0.59 to 0.46% CP.

Table 4. Ruminal, intestinal, and total Lys digestibility (%) in extruded and non-extruded feeds.

	Feed				CV (%)
	Corn	1% Germ	7% Germ	10% Germ	
	Ruminal digestibility				
Without extrusion	99.9 Aa	99.8 Ab	99.9 Aa	99.9 Aa	
With extrusion	99.9 Aa	99.8 Ab	99.8 Bb	99.9 Aa	0,0
	Intestinal digestibility				
Without extrusion	55.5 Aa	67.7 Aa	51.3 Ba	45.4 Aa	
With extrusion	48.9 Ab	54.1 Aab	74.4 Aa	54.7 Aab	16,6
	Total digestibility of dry matter				
Without extrusion	99.9 Aa	99.9 Aa	99.9 Aa	99.9 Aa	
With extrusion	99.9 Aa	99.9 Aa	99.9 Aa	100.0 Aa	0,1

Means followed by the same lower case letter in rows, and capital letters in columns, are not significantly different (Tukey test; P > .05).
Source: Elaboration of the authors.

The results of the present study are similar to those of Cozzi and Polan (1995), who compared the AA concentration in corn gluten after various incubation times. After 12 hours of incubation, with ruminal Lys decreased from 1.9% to 1.4% ($P < 0.05$), Met decreased from 2.6 to 2.1 ($P<0.10$), and Thr decreased from 4.4% to 3.6% ($P>0.05$).

Table 5. Ruminal, intestinal, and total Met digestibility (%) in extruded and non-extruded feeds.

	Feed				CV (%)
	Corn	1% Germ	7% Germ	10% Germ	
	Ruminal digestibility				
Without extrusion	37.4 Ab	51.7 ab	55.1 Aab	57.1 Aa	
With extrusion	51.7 Bab	53.9 ab	40.9 Bb	66.6 Aa	15.1
	Intestinal digestibility				
Without extrusion	74.5 Aa	82.3 Aa	80.6 Aa	45.4 Bb	
With extrusion	66.8 Ab	80.3 Aab	87.8 Aa	80.0 Aab	9.4
	Total digestibility of dry matter				
Without extrusion	84.0 Aab	91.4 Aa	91.3 Aa	76.7 Bb	
With extrusion	83.4 Ab	92.2 Aab	92.7 Aab	93.4 Aa	4.6

Means followed by the same lower case letter in lines, and capital letter in columns, are significantly different (Tukey test; P >.05).
Source: Elaboration of the authors.

Of concern when using in situ techniques is ruminal bacterial contamination. During incubation, bacteria and protozoa that invade the bag are bound to polyester and food particles (OLUBOBOKUN; CRAIG; NIPPER, 1988). We attempted to circumvent this problem by washing the bags in cold water after removal from the rumen. Microbial markers have been studied to find a reliable correction factor (BRODERICK; MERCHEN, 1992).

The ruminal digestibility of Met from food (Table 5) was statistically significant ($P < 0.05$), showing the greater availability of ruminal Met derived from corn germs than from corn. Foods CG1, CG7, and CG10 showed linear regression values for the total digestibility of Met ($P < 0.05$). Degradation of the Met in corn germ by ruminal microorganisms may have been favored by processing these byproducts. The digestibility of Met did not increase after extrusion, and the digestion of Met was similar ($P>0.05$) in all extruded germs.

These results suggest that the absorption of Met from grain can be high. This observation is based on the levels of total digestibility of Met from tested food. Extrusion can act as an adjuvant in the increase in digestion, although corn does not respond satisfactorily in this respect. The digestibility of Thr is listed in Table 6, which shows that the relative digestibility of Thr in extruded and non-extruded corn and corn byproducts is similar to that of Met.

The intestinal digestion observed in the present study is similar to that observed in previous studies. However, it can be difficult to make comparisons across studies because digestibility values are expressed in different ways. Erasmus, Botha and Meissner (1994) observed that corn gluten meal results in intestinal digesta with the following proportion of essential AA (g/100 g of AA): arginine (9.2), histidine (4.6), isoleucine (9.8), leucine (27.0), Lys (10.7), Met (5.8), phenylalanine (11.4), Thr (10. 52), and valine (11.0). Moreover, Coomer et al. (1993) compared sources of non-degradable

protein and observed that at the level of the abomasum, corn germ provided 108.6% of the daily requirement of Lys, whereas soybean meal provided 78.8%, treated soybean meal provided 89.6%, and soybean meal combined with corn germ provided 93 7% of the daily requirement of AA. Piepenbrink and Schingoethe (1998) estimated the intestinal absorption of corn gluten meal AA and found that the absorption of Lys, Met, and Thr was 3.0%, 2.6%, and 3.8% CP, respectively. In the present study, intestinal digestion was the largest contributor to the total digestibility of Met and Thr, and this showed linear regression for the germs without extrusion, except for the high Lys degradation in the rumen.

Table 6. Ruminal, intestinal, and total Lys digestibility (%) in extruded and non-extruded feeds.

	Feed				CV (%)
	Corn	1% Germ	7% Germ	10% Germ	
	Ruminal digestibility				
Without extrusion	45.9 Aa	48.0 Aa	49.7 Aa	50.1 Aa	
With extrusion	43.9 Aab	49.8 Aab	38.5 Bb	59.9 Aa	16.3
	Intestinal digestibility				
Without extrusion	68.7 Aa	68.6 Aa	64.8 Ba	45.4 Bb	
With extrusion	66.2 Aa	64.0 Aa	76.3 Aa	62.9 Aa	9.5
	Total digestibility of dry matter				
Without extrusion	83.0 Aa	83.6 Aa	82.4 Aab	72.9 Bb	
With extrusion	80.9 Aa	84.7 Aa	85.2 Aa	85.1 Aa	5.0

Means followed by the same lower case letter in rows, and capital letter in columns, are significantly different (Tukey test; P>.05).
Source: Elaboration of the authors.

Conclusions

Corn byproducts had greater DM digestibility than corn. The extraction of oil from corn can increase protein digestion. The extrusion process, depending on the amount of oil in the corn germ, may decrease the CP of the digestion products of corn. The Lys of corn germ and corn was highly availability to the animal. Met and Thr were sensitive to byproduct and extrusion processing.

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