Passage of nutrients into the duodenum and their postruminal digestion in cows fed crushed and ground maize

Z. Čerešňáková, M. Chrenková, A. Sommer

Research Institute of Animal Production, Institute for Animal Nutrition, Nitra, Slovak Republic

ABSTRACT: In an *in vivo* experiment the 2 × 2 Latin square method and Cr as a marker were used to determine ruminal degradation and postruminal digestion of nutrients from a feed ration containing 3 kg of crushed or ground maize (CM vs. GM). The experiment included 4 cows with rumen fistulae and duodenal T-cannulae. Amino acid passage to the duodenum was also determined. The mean concentration of ammonia nitrogen in the rumen fluid was 11.6 ± 6.22 and 11.5 ± 6.41 mg/100 ml in the CM and GM ration, respectively. Crushing considerably decreased starch degradation in the rumen where starch passage reached 33.5% with CM and only 21.5% with GM. Both post-ruminal (82.2% vs. 85.5%) and total digestibility of starch (94.0% vs. 96.8%) was high. The passage of other nutrients was not influenced by crushing. With both feed rations higher amounts of crude protein and amino acids passed to the duodenum than were ingested (127.8% vs. 130.4% and 118.1% vs. 124.5%, respectively). In comparison with intake the highest increase was observed in essential lysine (156.5% and 165.0%, respectively) and glycine (261.1% and 280.2%, respectively). Apparent crude protein digestibility was at the level of 68.5% (CM) and 67.2% (GM).

Keywords: crushed maize; ground maize; degradation of nutrients; passage of nutrients; postruminal digestion of nutrients

Since grains contain high levels of starch, they influence the effectiveness of utilisation of the whole feed ration of ruminants. There are considerable differences in the ruminal degradation of starch and crude protein from grains, maize, other concentrates and forages (Tamminga *et al*., 1990; Zebrowska *et al*., 1997; Čerešňáková *et al*., 2000). The extent of microbial proteosynthesis and supply of the animal not only with microbial protein but also with amino acids depend upon the amount of fermentable energy in the rumen (Owens *et al*., 1986; Huntington, 1997). For this reason synchronization of carbohydrate fermentation and release of nitrogen are of great importance for the synthesis of ruminal microbial proteins and their passage into the small intestine (Herrera-Saldana *et al*., 1990; Aldrich *et al*., 1993; Overton *et al*., 1998).

Our investigation focused on the determination of ruminal and postruminal digestibility of nutrients in animals fed balanced diets that contained crushed and ground maize. Simultaneously the passage of amino acids into the duodenum was examined.

MATERIAL AND METHODS

Animals and feeding

In the experiment 4 non-lactating cows with average live weight of 550 kg were used; the animals were fitted with large rumen fistulae and T-cannulae (Bar Diamont, Inc., USA) in the proximal duodenum (ca. 20 cm distal to the pylorus). The cows were fed the experimental diets twice a day (at 6:30 and 18:30). The diets contained 2.57 or 2.59 kg of dry matter of crushed or ground maize of the Svetlana hybrid, respectively. The amounts of the other components were balanced as follows: 2.9 kg DM of maize silage, 3.9 kg DM of lucerne hay, 0.19 kg DM of extracted ground soya, 0.09 kg DM of Vitamix S-Super. Feed consumption was recorded daily. Water was always available.

Experimental design and sampling

The experimental design was replicated Latin square with 2 treatments.

A 14-day adaptation period was followed by a pre-experimental period (two days) during which duodenal chyme and faeces were collected from the animals for the determination of Cr levels (blank). Chromic oxide was used as a marker of nutrient flow to the duodenum, apparent digestibility of nutrients in the rumen and total apparent digestibility. In the following 10 days and during the main sampling period (5 days) the animals received 100 g of Cr marker in four portions (4 × 25 g at 6 a.m., 12 a.m., 6 p.m., 12 p.m.) per animal and day. Samples of duodenal chyme were obtained via the duodenal T-cannula by the method of Rohr *et al*. (1979) every two hours and collected into a bulk 24 hour sample which was then stored at – 20°C until processing. Faeces of every defecation in the course of 24 hours were collected into a mean daily sample and after thorough mixing 4% of the total amount was taken as the mean sample. The aliquots of the mean faeces and duodenal chyme were freeze-dried and used for Cr and nutrient level determination. After sampling of duodenal contents was finished, ruminal fluid was collected for two days by means of a ruminal fistula prior to the morning feeding and 1, 3, 6 and 8 hours after feeding.

Chemical analyses

Weender analysis (STN 46 7092) and van Soest method (Lutonská and Pichl, 1983) were used to measure nutrient levels as well as NDF and ADF, respectively, in feed samples, remainders, duodenal chyme and faeces. Starch content was measured by the method of Salomonsson (1984). Amino acid levels were determined after acid hydrolysis with 6 M HCl whereas those of sulphur-containing amino acids were determined after oxidation hydrolysis using the automatic amino acid analyser AAA 400 (INGOS Prague, CR). Ammonia concentration was determined by the Conway method and Cr concentrations by the AAS Solar 9000 (Unicam Cambridge, UK).

Mathematical and statistical processing

All parameters investigated *in vivo* were evaluated for each animal and treatment by ANOVA analysis. Significance of differences was declared at $P < 0.05$ and $P < 0.01$.

RESULTS

The chemical composition of the feeds is given in Table 1. Since N-levels in the lucerne hay were lower than in traditional good-quality hay, extracted soybean meal was added to balance crude protein in the feed ration. Feed intake was not influenced by the treatment of maize, and 26.6% and 26.8% proportions of maize grain in the dry matter of the feed ration had no effect upon ruminal pH values. The mean pH of rumen fluid was 6.7 with both types of maize treatment.

Maximum ammonia levels in the rumen fluid were observed as early as 1 hour after feeding both CM and GM. The mean respective concentrations of ammonia-N reached 11.6 ± 6.22 and 11.5 ± 6.41 mg per 100 ml. The dynamics of ammonia-N release took a typically physiological course (Figure 1).

Table 1. Mean chemical composition of experimental feeds (g/kg DM)

Nutrients	Crushed maize	Ground maize	Soybean meal	Maize silage	Lucerne hay
Dry matter (g/kg)	857	866	894	362	889
CP (N × 6.25)	95	98	509	79	169
NDF	51	45	84	442	490
ADF	44	35	77	231	431
Hemicelluloses	7	10	7	211	59
Starch	657	655	65	305	51
Organic matter	984	986	927	956	929

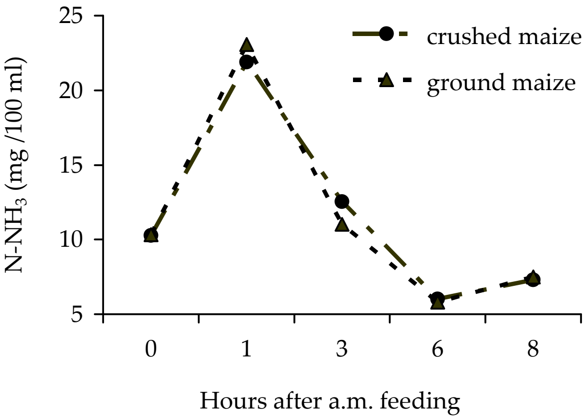

Figure 1. Changes of ammonia-N concentration in the rumen fluid when feeding a ration containing crushed or ground maize

Starch and organic matter intake and digestibility are summarized in Table 2. Starch passage through the duodenum was significantly higher with crushed maize ($P < 0.01$) than with ground maize. Lower ruminal starch degradation of CM than GM was also confirmed by *in sacco* results (Čerešňáková *et al*., in press). From the total amount ingested as much as 33.5% (i.e. 970 g starch per day) passed into the duodenum. In animals fed ground maize only 21.2% (i.e. 686 g) took the same course. Post-ruminal digestibility of by-pass starch was high (82.2 and 85.5%, respectively, with CM and GM) similarly like the total digestibility of starch. The difference between CM and GM (94.0 vs. 96.8%) was significant ($P < 0.05$).

Table 3 contains data on the digestibility of NDF, ADF and hemicellulose. In the rumen, 65.0% and 62.8% NDF and 73.8% and 73.0% of hemicellulose were degraded from the CM- and GM-containing ration, respectively. The differences in the total NDF digestibility and/or ADF between both rations were significant. Lowest ruminal degradation was observed with the ADF fraction compared to NDF (CM 59.7%, GM 57.0%); it was also the case of total tract digestibility of ADF (63.6% and 58.8% of the ingested amount of ADF).

Passage and digestibility of crude protein are documented in Table 4. The animals ingested on average 1 182 g per day, but the passage to the duodenum increased about 30%. This increase occurred with both treatments. Daily postruminal digestion of crude protein reached 1 111.8 and 1 137.1 g,

Table 2. Passage of organic matter and starch and their apparent digestibility in the digestive tract of cows

Index	Feed rations		Significance of differences
	crushed maize	ground maize	
Organic matter			
Intake (g/day)	8 818	9 118	n.s.
Passage from rumen (% of intake)	59.3	57.6	
Digested			
– in the rumen (% of intake)	40.7	42.4	n.s.
– postruminally (% of passage to duodenum)	56.5	54.1	n.s.
Total tract apparent digestibility (%)	74.3	73.5	n.s.
Starch			
Intake (g/day)	2 917	3 250	n.s.
Passage from rumen (% of intake)	33.5	21.2	**
Digested			
– in the rumen (% of intake)	66.5	78.8	**
– postruminally (% of passage to duodenum)	82.2	85.5	n.s.
Total tract apparent digestibility (%)	94.0	96.8	*

*$P < 0.05$; **$P < 0.01$; n.s. at $P > 0.05$

Table 3. Passage of NDF, ADF and hemicelluloses and their apparent digestibility in the digestive tract in cows

Index	Feed ration		Significance of differences
	crushed maize	ground maize	
NDF			
Intake (g/day)	3 927	3 997	n.s.
Passage from rumen (% of intake)	35.0	36.7	n.s.
Digested			
– in the rumen (% of intake)	65.0	62.8	n.s.
– postruminally (% of passage to duodenum)	12.0	7.4	**
Total tract apparent digestibility (%)	69.2	65.2	*
ADF			
Intake (g/day)	2 448	2 501	n.s.
Passage from rumen (% of intake)	40.3	43.0	n.s.
Digested			
– in the rumen (% of intake)	59.7	57.0	n.s
– postruminally (% of passage to duodenum)	9.8	4.6	**
Total tract apparent digestibility (%)	63.6	58.8	*
Hemicelluloses			
Intake (g/day)	1 496	1 527	n.s.
Passage from rumen (% of intake)	26.1	27.0	n.s.
Digested			
– in the rumen (% of intake)	73.8	73.0	n.s.
– postruminally (% of passage to duodenum)	15.1	13.6	n.s.
Total tract apparent digestibility (%)	77.8	76.6	n.s.

$^{*}P < 0.05$; $^{**}P < 0.01$; n.s. at $P > 0.05$

respectively, which represents 75.1% and 74.5% of the amount passing to the duodenum, respectively. Total apparent digestibility of crude protein was 68.5% with the CM ration and 67.2% with the GM ration.

Amino acid analysis also confirmed the flow of crude protein to the duodenum to be increased in comparison with amino acid levels in the feed ration (Tables 5 and 6). With the CM and GM rations the animals ingested 877.1 and 868.0 g of amino acids in 24 hours. Except for histidine, methionine and proline the amounts of amino acids passing to the duodenum were higher than their intake. With both rations the most pronounced increase was seen in lysine (156.5 vs. 165.0%) and glycine (261.1 vs. 280.2%). There was no significant effect of maize treatment on the passage of total essential and non-essential amino acids (Table 6).

DISCUSSION

Ruminal digestion is a dynamic process that largely depends on the type and amount of carbohydrate sources ingested by the animal. The effectiveness of nutrient utilisation by ruminal microorganisms and in the whole digestive tract can be improved by suitable treatment of grains. When crushed maize was replaced by ground maize, starch degradation in the rumen increased whereas passage into the

Table 4. Passage and apparent digestibility of crude protein in the digestive tract

Index	Feed ration		Significance of differences
	crushed maize	ground maize	
Crude protein (N × 6.25)			
Intake (g/day)	1 178	1 187	n.s.
Passage to duodenum (g/24 h)	1 503	1 518	n.s.
– out of intake (%)	127.8	127.9	n.s.
Digested			
– postruminally (g/24 h)	1 111.8	1 137.1	
– out of passage to duodenum (%)	75.1	74.5	n.s.
Total tract apparent digestibility (%)	68.5	67.2	n.s.

n.s. at $P > 0.05$

Table 5. Intake of amino acids (g/24 h) with feed rations containing crushed and ground maize

Amino acids	Crushed maize $x \pm s_x$	Ground maize $x \pm s_x$	Significance
Thr	37.0 ± 2.1	37.9 ± 1.0	n.s.
Val	47.1 ± 2.3	48.2 ± 1.1	n.s.
Ileu	37.2 ± 4.8	37.1 ± 0.8	n.s.
Leu	84.1 ± 4.4	82.6 ± 1.5	n.s.
Tyr	36.0 ± 0.7	35.3 ± 0.1	n.s.
Phe	45.8 ± 2.3	45.9 ± 0.9	n.s.
His	26.8 ± 1.5	27.1 ± 0.6	n.s.
Lys	42.8 ± 2.4	43.2 ± 2.1	n.s.
Arg	39.2 ± 2.4	40.3 ± 0.8	n.s.
Met	18.6 ± 0.8	18.5 ± 0.9	n.s.
ΣEAA	414.8 ± 20.2	416.0 ± 9.7	n.s.
Cys	14.9 ± 0.6	14.8 ± 0.9	n.s.
Asp	105.5 ± 5.8	107.2 ± 3.3	n.s.
Ser	43.7 ± 3.1	44.6 ± 1.4	n.s.
Glu	125.1 ± 7.4	122.5 ± 2.1	n.s.
Pro	79.0 ± 4.3	78.4 ± 2.2	n.s.
Gly	35.7 ± 1.6	36.0 ± 0.3	n.s.
Ala	58.4 ± 2.9	58.9 ± 1.2	n.s.
ΣneAA	462.3 ± 24.1	462.4 ± 11.2	n.s.
ΣAA	877.1 ± 44.3	868.0 ± 35.5	n.s.

n.s. insignificant at $P > 0.05$

Table 6. Amino acid passage to the duodenum in g per 24 h and in % of intake

Amino acids	Crushed maize (n = 4)		Ground maize (n = 4)		Significance of differences
	g/24 h	% of intake	g/24 h	% of intake	
Thr	57.2 ± 2.09	152.6 ± 10.71	60.5 ± 3.92	158.4 ± 7.74	n.s.
Val	51.5 ± 2.57	107.4 ± 8.13	53.3 ± 2.91	110.2 ± 4.35	n.s.
Ileu	44.3 ± 1.77	118.1 ± 7.52	46.1 ± 2.42	123.4 ± 4.99	n.s.
Leu	88.4 ± 3.37	103.9 ± 5.75	92.4 ± 5.02	110.2 ± 4.43	n.s.
Tyr	42.3 ± 2.38	114.1 ± 6.60	44.0 ± 3.37	123.7 ± 10.05	n.s.
Phe	48.5 ± 1.63	103.9 ± 7.99	49.4 ± 2.20	107.7 ± 4.10	n.s.
His	21.4 ± 0.69	79.3 ± 5.80	22.3 ± 1.19	81.5 ± 3.37	n.s.
Lys	68.7 ± 3.20	156.5 ± 14.86	70.8 ± 4.15	165.0 ± 8.29	n.s
Arg	54.9 ± 1.34	133.0 ± 9.40	51.0 ± 13.04	122.9 ± 29.95	n.s.
Met	14.8 ± 1.40	82.2 ± 4.33	16.5 ± 2.42	88.7 ± 9.80	n.s.
ΣEAA	492.0 ± 18.19	113.9 ± 11.05	506.3 ± 37.13	120.7 ± 6.88	n.s.
Cys	15.3 ± 1.26	107.4 ± 3.77	16.7 ± 1.93	111.9 ± 7.94	n.s.
Asp	115.1 ± 3.95	108.0 ± 6.98	122.5 ± 8.31	113.7 ± 5.49	n.s.
Ser	58.5 ± 2.73	133.1 ± 10.88	62.0 ± 4.85	138.1 ± 8.22	n.s.
Glu	134.4 ± 13.40	114.2 ± 5.67	152.1 ± 9.29	121.7 ± 6.05	n.s.
Pro	56.0 ± 3.11	72.4 ± 1.43	60.6 ± 4.63	74.6 ± 4.95	n.s.
Gly	97.9 ± 10.34	261.1 ± 17.05	106.0 ± 13.77	280.2 ± 40.70	n.s.
Ala	71.4 ± 2.67	120.6 ± 7.65	75.7 ± 5.23	127.3 ± 7.12	n.s.
ΣneAA	548.6 ± 19.07	118.0 ± 7.76	595.7 ± 41.06	124.5 ± 6.74	n.s.
ΣAA	1 040.6 ± 34.71	118.1 ± 6.93	1 114.6 ± 102.8	124.8 ± 6.57	n.s.

n.s. insignificant at $P > 0.5$

duodenum decreased. This became evident in increased ruminal degradation of organic matter.

In our experiment total NDF degradation amounted to 69.2% and 65.2% with the lower value associated with GM feeding. A substantial part of the ingested amounts of NDF and ADF was degraded in the rumen since in the small intestine there are no enzymes that would ensure digestion of structural carbohydrates. Postruminal digestion of the latter only occurs by the microflora in the caecum or the large intestine. According to our observations 7.4–12.0% of NDF passing to the duodenum were digested postruminally. Low postruminal digestibility of NDF and ADF (9.2–14.2 and 5.7–10.1%, respectively) was also observed by other authors (Joy *et al*., 1997) in an experiment with heat-processed maize using rations similar to ours. According to Poore *et al*. (1993) decreased digestion of structural carbohydrates occurs during grain feeding in cases when the NDF-to-degraded starch ratio in the rumen is below 0.9–1.0, which also leads to a decrease in ruminal pH. In our experiment the above ratio was higher than 1 and the pH value of the ruminal fluid did not drop below 6.2. Of the cell wall fractions hemicellulose seemed to be the best digested one (digestibility values between 76.6 and 77.8%).

Several authors have reported a flow of crude protein into the duodenum of cows that was higher than the crude protein intake with maize, wheat, barley or tapioca grains as starch sources. Lebzien *et al*. (1983) reported N-passage to the duodenum to reach as much as 126% of the ingested amount. With feed rations containing maize or wheat Matthé (2001) reported an N-passage into the duodenum of 124 and 118%. Similarly our experiments revealed the passage of crude protein from the rumen during CM and GM passage to be substantially higher than the crude protein intake (127.8% and 127.9%, respectively).

These data document the utilisation of nitrogen released by degradation of both the feed-contained crude protein and urea nitrogen from the rumeno-hepatic cycle in microbial synthesis of proteins in the rumen. Endogenous N also contributes to increased passage of N from the rumen. The extent of microbial proteosynthesis in the rumen depends on the amount of digested saccharides in the rumen given as the amount of fermentable organic matter (kg) or MJ ME. Since the amount of microbial protein has not been determined, based on the passage of amino acids we can only state the synthesis of microbial protein contributes to the total nitrogen passed to the duodenum. The most suitable starch source (maize, wheat, barley or other grains) and/or treatment as a source of energy for microbial protein synthesis has not yet been confirmed and remains a subject of discussion

Several authors have documented lower passage of microbial protein to the duodenum when the animals were fed maize in comparison with wheat, barley and tapioca (Lebzien and Engling, 1995), wheat (Lebzien *et al*., 1983; Matthé *et al*., 2000), whereas Kung *et al*. (1992) did not identify any influence of starch source.

The largest portion of nitrogen passing from the rumen to the duodenum consists of nitrogen from microbial protein, the digestibility of which is high and almost constant (80–85%), a smaller part consists of undegraded crude protein of the feed, the digestibility of which is different (Čerešňáková *et al*., 2002). In our experiment despite of high postruminal digestibility of N substances (75.1 and 74.5% with CM and GM, respectively) the total digestibility of crude protein reached only 68.5% and 67.2% with CM and GM, respectively. According to Lebzien and Engling (1995) there is a negative relationship between the NAN amount passed to the duodenum relative to crude protein intake and crude protein digestibility ($r = -0.80$). If more non-ammonia-nitrogen (NAN) as a percentage of crude protein intake enters the duodenum, then total apparent crude protein digestibility is lower.

Amino acids represent a considerable part of crude protein intake. With the exception of histidine, methionine and non-essential proline, the passage of amino acids to the duodenum was higher than their intake. Total amino acid passage to the duodenum was 118.1% and 124.8% of the ingested amino acids whereas essential amino acid passage amounted to 113.9% and 120.7% with CM and GM, respectively.

The highest increase in comparison with intake was observed in essential lysine and non-essential glycine (Table 6). Joy *et al*. (1997) stated a similar tendency in the proportion of these amino acids in the duodenal chyme when maize was fed at 24% of the dry matter in the ration. It is known from literary data that microbial protein provides as much as 81.8 g lysine daily (daily lysine requirement of dairy cows 99.7 g producing as much as 30 kg milk/day) when dietary intake meets energy requirements for the maintenance and production of 30 kg milk (Boisen *et al*., 1998). Sulphur-containing amino acids, mainly methionine, which is also essential for dairy cows, accounted for 82.2% and 88.7% of the total ingested amount, i.e. in absolute values for 14.8 g and 16.5 g in 24 hours.

Finally it can be stated that the feeding of crushed maize positively affected ruminal degradation and total digestibility of cell walls. Starch degradability in the rumen significantly decreased in comparison with the feeding of ground maize but intestinal digestibility was high with ground and crushed maize. The relation of energy and available nitrogen in the rumen resulted in the increased passage of nitrogen and amino acids to the duodenum towards nitrogen and amino acid intake.

Acknowledgements

The authors wish to thank Mrs. Gertruda Gréserová, M.A., for translating the manuscript into English.

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Received: 03–08–14
Accepted after corrections: 04–04–19

ABSTRAKT

Pasáž živín do duodena a ich postruminálne trávenie u kráv kŕmených miaganou a šrotovanou kukuricou

V pokuse *in vivo* metodou latinského štvorca 2 × 2 sme sledovali na 4 kravách s bachorovými fistulami a duodenálnymi T kanylami pomocou Cr ako markera ruminálnu degradáciu a postruminálnu stráviteľnosť živín kŕmnej dávky s obsahom 3 kg miaganej (KM) alebo šrotovanej kukurice (KŠ). Stanovili sme tiež pasáž aminokyselín do duodena. Priemerná koncentrácia amoniakálneho N v bachorovej tekutine bola 11,6 ± 6,22 resp. 11,5 ± 6,41 mg/100 ml (pri KM resp. KŠ). Miaganím kukurice sa významne znížila degradácia škrobu v bachore a jeho pasáž bola 33,5 % z prijatého množstva kým pri kukurici šrotovanej len 21,5 %. Postruminálna (82,2 % resp. 85,5 %) i celková stráviteľnosť škrobu bola vysoká (94,0 % resp. 96,8 %). Pasáž ostatných živín nebola miaganím ovplyvnená. Pri oboch kŕmnych dávkach sme stanovili vyššiu pasáž N-látok i aminokyselín do duodena ako bolo prijatých (127,8 % resp. 130,4 % a 118,1 % resp. 124,5 %). Najvyšší prírastok v porovnaní s príjmom sme zaznamenali pre esenciálny lyzín (156,5 % resp. 165,0 %) a neesenciálny glycín (261,1 % resp. 280,2 %). Zdánlivá stráviteľnosť N-látok bola na úrovni 68,5 % pre KM a 67,2 % pre KŠ.

Kľúčové slová: kukurica miaganá; kukurica šrotovaná; degradácia živín; pasáž aminokyselín; postruminálna stráviteľnosť živín

Corresponding Author

Ing. Zuzana Čerešňáková, CSc., Výzkumný ústav živočíšnej výroby, Hlohovská 2, 949 92 Nitra,
Slovenská republika
Tel. +421 37 654 62 25, fax +421 37 654 64 18, e-mail: ceresnak@vuzv.sk