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Influence of Wheat and Maize Starch on Fermentation in the Rumen, Duodenal Nutrient Flow and Nutrient Digestibility

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Abstract

We investigated the effects of feeding diets with different starch sources on fermentation in the rumen, duodenal nutrient flow and nutrient digestibility. The basis of the diets was maize silage and alfalfa hay supplemented with wheat meal in diet W, or maize meal in diet M. The experiment was performed on four Black-Spotted bulls with mean live weight of 525 kg, which were fed twice daily at 06.30 and 18.30 h. Experimental animals were fitted with ruminal fistulae and duodenal T-shaped cannulae. Cr_2O_3 was used as a marker of nutrient flow to the duodenum. Rations were formulated so that the ratio of starch to crude fibre (CF) was 2.1:1 and the percentage of CF was maintained at 17% (DM). Duodenal chymus was collected at 2-h time intervals. Starch origin significantly affected ruminal fermentation. Concentration of propionic, butyric and lactic acid was higher with wheat than with maize meal. When the maize meal was the source of starch there was a significantly higher flow of fat, CF, nitrogen-free extract, and starch into duodenum. Differences in duodenal flow of crude protein were not significant across the starch sources. Intake of wheat meal or maize meal increased duodenal flow relative to intake by 33% or 42% respectively. The apparent digestibility of dry matter (76 ± 2%), crude protein (67 ± 0.9%), CF (64 ± 1.9%), nitrogen-free extract (82 ± 1.5%) and organic matter (76 ± 1.3%) was significantly higher by offering wheat meal.

Concentrates, carbohydrate, digestion, ruminants, duodenum

Carbohydrates are an important nutrient in dairy cow diets. The variability of non-structural carbohydrates degradation in the rumen influences the fermentation process (Kováčik et al. 2002), passage of nutrients into small intestine (Čerešňáková et al. 2006) and nutrient digestibility in ruminants (Pajtáš et al. 2003). The energy efficiency of starch fermented in the rumen to volatile fatty acids is lower than that of starch absorbed in the small intestine (Weurding and Poel 1998). Therefore, the increase of starch and its flow into the small intestine is important for energy supply to high-yielding dairy cows consuming large amounts of dietary starch from various feedstuffs. Depending on the starch source and amount, approximately 50-95% of dietary starch is fermented to volatile fatty acids (Sniffen et al. 1992). Starch fermentation in the rumen results in approximately a 40% decline in caloric efficiency compared to enzymatic starch digestion in the small intestine (Owens et al. 1986). The rate and extent of starch digestion in the rumen are affected by the structure of starch in the individual grain types (French 1973; Kotarski et al. 1992). In addition, there are large differences among cereals in starch degradability within the rumen. According to many authors, wheat starch degradability in the rumen is higher than that of maize starch (Lebzien and Engling 1995; Zebrowska et al. 1997; Kopčeková and Čerešňáková 2003; Čerešňáková et al. 2006).

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The objective of the present work was to investigate the influence of dietary starch sources (wheat and maize with constant starch to CF ratio of 2.1:1) on fermentation within the rumen, and duodenal flow and the digestibility of nutrients.

Materials and Methods

Animals and feeding

Four bulls of the Black-Spotted cattle breed with average live weight of 525 ± 32 kg were used in the experiment. Animals were fitted with a rumen fistula (Bar Diamont, Inc. USA) and a duodenal T-shaped cannula in the proximal duodenum (ca 20 cm distal to the pylorus). The bulls were fed individually two times daily at 06.30 and 18.30 h. Water was available *ad libitum*. Two diets supplemented with wheat or maize meal were used in the experiment (Table 1). The basal diet consisted of maize silage and alfalfa hay. Contents of dry matter, energy and nutrients in the diets are shown in Table 1. The ratio of starch to CF was held constant in both diets (Table 2).

Table 1. Ingredient and nutrient composition of the experimental diets

Ingredient	Diets W kg DM	M %	kg DM	%
Maize silage	5.0	50	4.7	47
Alfalfa hay	1.6	16	1.9	19
Wheat meal	3.4	34	-	-
Maize meal	-	-	3.4	34
Total	10.0	100	10.0	100
Chemical composition of dietary ingredients				
Feed n = 6	Maize silage	Alfalfa hay	Wheat meal	Maize meal
DM $g \cdot kg^{-1}$ FM	356	888	881	892
NEL $MJ \cdot kg^{-1}$ DM	6.29	4.65	8.80	9.00
NEV $MJ \cdot kg^{-1}$ DM	6.28	4.26	9.54	9.78
PDI $g \cdot kg^{-1}$ DM	52	107	94	66
CP $g \cdot kg^{-1}$ DM	86	178	149	90
Fat $g \cdot kg^{-1}$ DM	31	22	17	41
NFE $g \cdot kg^{-1}$ DM	624	382	776	825
Starch $g \cdot kg^{-1}$ DM	273	36	612	701
CF $g \cdot kg^{-1}$ DM	213	319	33	29
OM $g \cdot kg^{-1}$ DM	954	901	976	985
Ash $g \cdot kg^{-1}$ DM	46	99	24	15

DM – dry matter
FM – fresh matter
NEL – net energy of lactation
NEV – net energy of gain
PDI – protein digestible in intestine
CP – crude protein
NFE – nitrogen-free extract
CF – crude fibre
OM – organic matter

Experimental design and sampling

After the adaptation period of 11 days, the sampling period lasted 4 days. Chromic oxide was used as a marker of nutrient flow to the duodenum. In the adaptation period and during the sampling period, all animals received 100 g of Cr marker in 4 portions (4 × 25 g at 6:00 h, 12:00 h, 18:00 h, 24:00 h) per day. The marker was wrapped in filter paper and placed in the rumen via the rumen fistula. Samples of duodenal chymus were obtained via the duodenal T-cannula (Rohr et al. 1979) every 2 h and collected into a 24-h sample which was then stored at -20 °C until analysis. Ruminal fluid was collected for 3 days prior to the morning feeding and 1, 2, 4 and 6 h after feeding. During the experimental period, faeces were collected over 24-h collection periods. Before the morning feed, a subsample of 3% of the 24-h faecal collection was taken for chemical analysis.

Table 2. Intake (per day) of dry matter, energy and nutrients from the different diets

Intake			Diet	
			W	M
DM		g	8958	9261
Energy	NEL	MJ	61.9	63.0
	NEV	MJ	63.2	64.7
Nutrients	PDI	g	664	627
	Crude protein	g	1079	977
	Fat	g	225	292
	Nitrogen-free extract	g	5711	5844
	Starch	g	3115	3386
	Crude fibre	g	1501	1592
	Organic matter	g	8516	8704
Ratio of starch to fibre			2.1:1	2.1:1
Percentage of fibre			16.8	17.2

DM – dry matter
NEL – net energy of lactation
NEV – net energy of gain
PDI – protein digestible in intestine

Chemical analyses

Chemical composition of feeds and duodenal freeze-dried samples was determined by Weende analysis (Regulation of the Slovak Ministry of Agriculture no. 1497/4/1997-100). Starch was determined by the enzymatic method according to Salomonsson et al. (1984). Ruminal fluid pH was measured immediately after sampling, VFA concentration was determined using gas chromatography on a 1.8 m column with 10% SP1200 and 1% H_3PO_4 on Chromosorbe WAW 80/100 mesh with isocaprylic acid as an internal standard (GC Carlo Erba). Ammonia concentration was measured by the Conway method (Voight and Steger 1967). Concentration of Cr duodenal samples was determined by AAS (Solar 9000 Unicam Cambridge UK) according to the procedure of Williams et al. (1962).

Mathematical and statistical processing

Differences between treatments were evaluated by *t*-test using Statgraphics, Version 5.0 software. Statistical differences were declared significant at $P \leq 0.05$ and $P \leq 0.01$.

Results and Discussion

In our experiment the proportion of wheat meal and maize meal in the dry matter of the feed rations was 34% (Table 1). Intake of dry matter, energy and nutrients from the rations is shown in Table 2. The ratio of starch to fibre was held constant at 2.1:1 and the percentage of CF was maintained at 17% (DM).

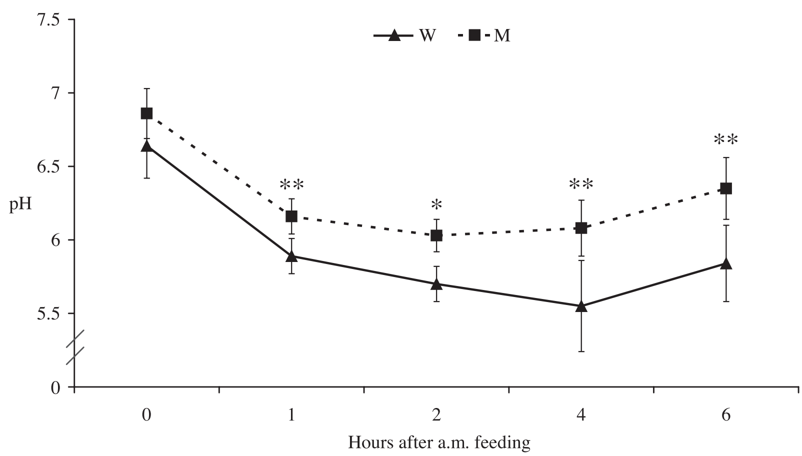

Fig. 1. Changes of pH in the rumen fluid when feeding a ration containing wheat (▲) or maize (■) meal, ** P ≤ 0.05; ** P ≤ 0.01*

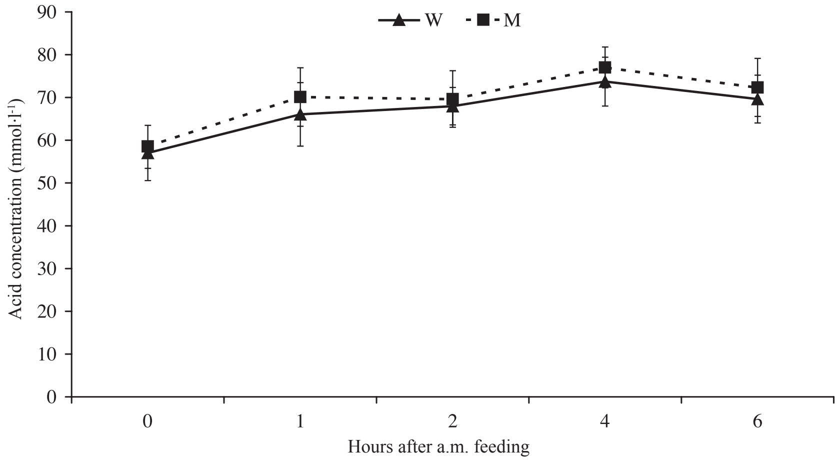

Fig. 2. Changes of acetic acid concentration in the rumen fluid (mmol·l^{-1}) when feeding a ration containing wheat (▲) or maize (■) meal

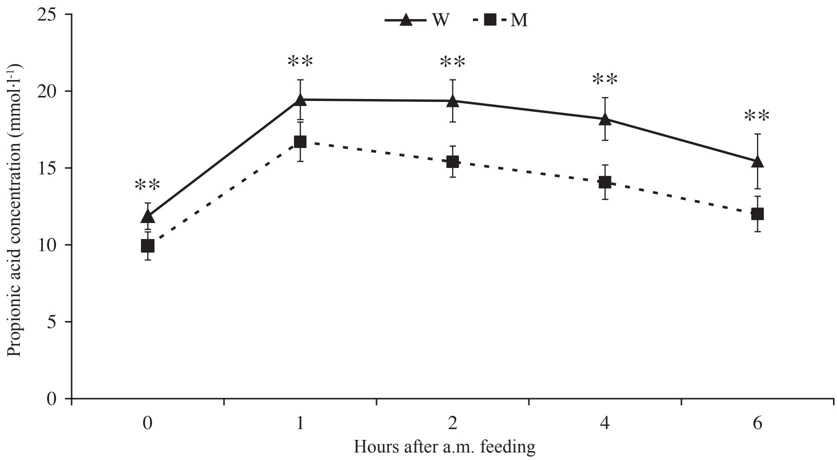

Fig. 3. Changes of propionic acid concentration in the rumen fluid (mmol·l^{-1}) when feeding a ration containing wheat (▲) or maize (■) meal, $* P \leq 0.05; ** P \leq 0.01$

Large amounts of fermentable starch included in rations reduce ruminal pH (Fig. 1) as a consequence of increased concentrations of propionic, butyric and lactic acid (Fig. 5) (De Visser et al. 1980; Plaizier et al. 2008). Propionic acid, which is produced by starch fermenting bacteria (Ørskov 1986; Čerešňáková et al. 2006), reached a maximal concentration within 1 h after feeding (Fig. 3). The diet with wheat meal caused an increase in the concentration of butyric acid (Fig. 4). The concentration of butyric acid was significantly higher with wheat meal than with maize meal. *In sacco* results with maize grain show a slower degradation of the crude protein compared to other cereals (Tamminga et al. 1990; Zebrowska et al. 1997; Čerešňáková et al. 2000). In contrast, the increased disappearance of N from wheat meal resulted in an increase in $N\text{-}NH_3$ concentration within the rumen fluid after the morning feeding (Fig. 6).

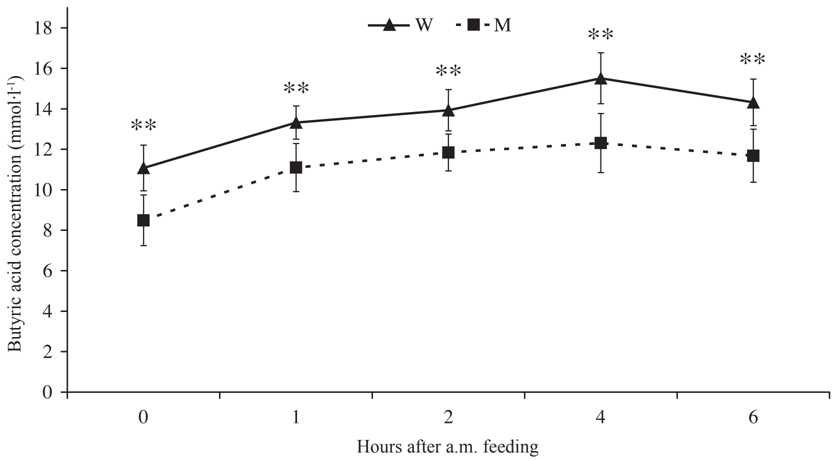

Fig. 4. Changes of butyric acid concentration in the rumen fluid (mmol·l^{-1}) when feeding a ration containing wheat (▲) or maize (■) meal, * *P ≤ 0.05; *** *P ≤ 0.01*

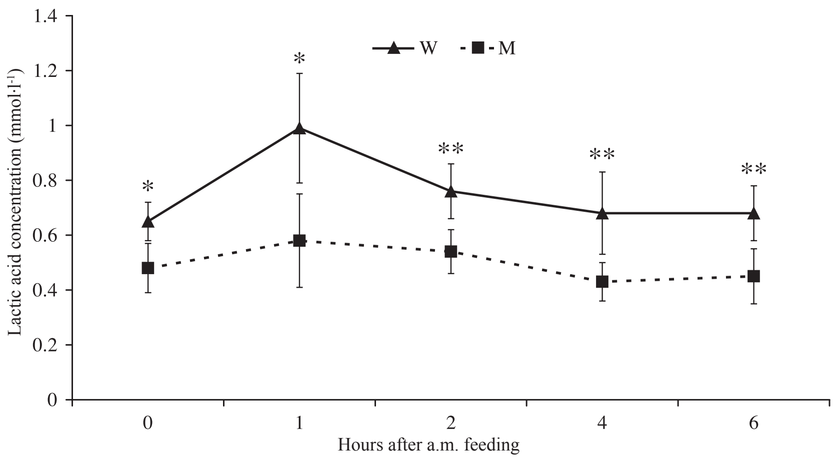

Fig. 5. Changes of lactic acid concentration in the rumen fluid (mmol·l^{-1}) when feeding a ration containing wheat (▲) or maize (■) meal, * *P ≤ 0.05; *** *P ≤ 0.01*

Influence of maize and wheat meal on duodenal nutrient flow is shown in Fig. 7. Significantly higher duodenal flow of all nutrients was observed with the exception of CP with the maize diet. The rate of organic matter degradation in the rumen and its passage into the small intestine in cereals is determined primarily by starch concentration. Matthé et al. (1999) determined a high correlation between organic matter and starch degradability (R = 0.99). Similarly we observed significantly higher flow of organic matter into small intestine with the maize diet. Jochman (1998) reported that starch source in diets influences starch flowing into small intestine. In our experiment a higher starch passage (399 g/d) was observed when maize-based starch was used. The duodenal flow of starch from the maize represented 12% and 6% of the dietary starch intake, respectively (Table 3). This result corresponds with results from several authors (Lebzien and Engling 1995; Zebrowska

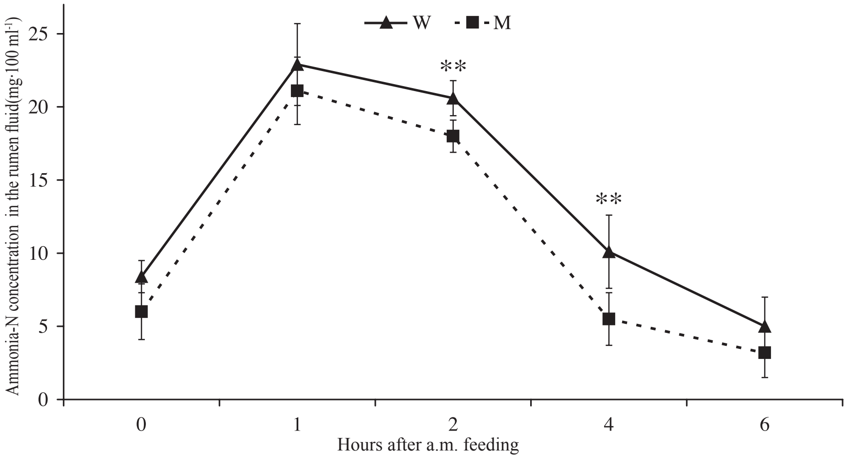

Fig. 6. Changes of ammonia-N concentration in the rumen fluid (mg·100 ml^{-1}) when feeding a ration containing wheat (▲) or maize (■) meal, * *P ≤ 0.05; *** *P ≤ 0.01*

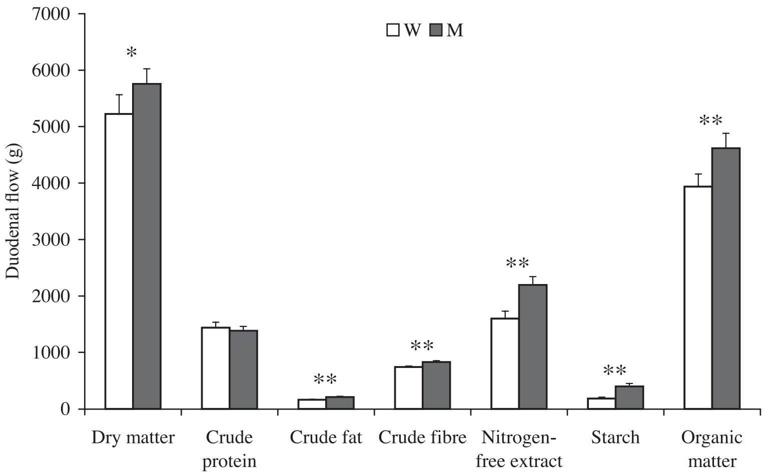

Fig. 7. Duodenal flow of dry matter and nutrients for 24 h (g) when feeding a ration containing wheat (white column) or maize (grey column) meal, * *P ≤ 0.05; *** *P ≤ 0.01*

et al. 1997). An increased proportion of non-degradable starch and its flow into the small intestine are very important for the energetic efficiency of highly productive dairy cows. During our experiment, the animals ingested 3115 g/d of starch from wheat meal (diet W) and its rumen degradability was 94%. Whereas the intake of maize starch (diet M) was 3386 g/d and the degradation in the rumen was 88%. Similar results were reported by (Huntington 1997; Čerešňáková et al. 2003; Kopčeková and Čerešňáková 2003; Čerešňáková et al. 2006).

Differences in duodenal flow of crude protein depending on diets were not significant. When wheat meal was used as the starch source, the duodenal flow of crude protein was 1437 g in 24 h; whereas that of maize meal was 1383 g in 24 h. Lebzien et al. (1983) reported that feeding maize decreased microbial protein synthesis in the rumen, however,

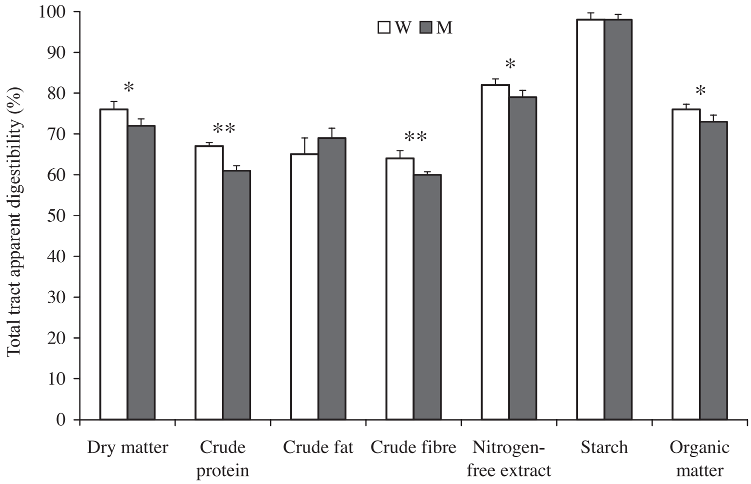

Fig. 8. Total tract apparent digestibility of nutrients (%) when feeding a ration containing wheat (white column) or maize (grey column) meal, * *P ≤ 0.05; ** P ≤ 0.01*

Table 3. Passage of starch and crude protein and their apparent digestibility in the digestive tract

Index	Diets		*P* - value
	W	M	
Starch			
Intake (g/24 h)	3115	3386	*
Passage to duodenum (g/24 h)	180	399	**
% of intake	6	12	**
Digested			
in the rumen (% of intake)	94	88	*
post ruminally (% of passage to duodenum)	71	80	*
Crude protein (N × 6.25)			
Intake (g/24 h)	1079	977	n.s.
Passage to duodenum (g/24 h)	1437	1383	n.s.
as % of intake	133	142	n.s.
Digested			
post ruminally (g/24 h)	1078	1005	n.s.
out of passage to duodenum (%)	75	73	n.s.

* *P ≤ 0.05; ** P ≤ 0.01*; n.s. *P > 0.05*

the proportion of feed crude protein in the small intestine increased. The duodenal flow of crude protein was higher than the respective intakes with our diets.

The impact of maize and wheat meal on total tract apparent digestibility of nutrients is shown in Fig. 8. Nutrient digestibility was influenced by the different starch sources. The apparent digestibility of dry matter (76%), crude protein (67%), fibre (64%), nitrogen-free extract (82%) and organic matter (76%) was significantly higher by offering wheat meal. The apparent digestibility of starch was not significantly influenced by the different starch sources. In both cases, starch digestibility was 98% despite different starch intakes (in diet W starch intake was 3115 g per day, in diet M it was 3386 g per day). From previous research, we know that apparent digestibility of starch is not significantly affected by diet at low intakes. Reynolds et al. (1997) did not detect any influence on starch digestibility with rations providing a starch intake of 4-11 kg per day. Also, Beckman and Weiss (2005) did not detect significant differences in starch digestibility when the intake of starch in rations varied. De Visser (1980), Klejmenov et al. (1986), and Robinson et al. (1987) reported that by increasing the ratio of starch in feeding rations increases the digestibility of organic matter and crude protein. However, the source of starch in the diet may influence this response.

In conclusion, different starch sources (wheat and maize) significantly changed ruminal pH, as a consequence of increased concentrations of propionic, butyric and lactic acid. The concentrations of propionic, butyric and lactic acid were significantly higher with wheat meal than with maize meal. When maize meal was used as the starch source, the duodenal flow of fat, fibre, nitrogen-free extract and starch was significantly higher. Differences in duodenal flow of crude protein were not significant depending on the starch sources. The apparent digestibility of dry matter, crude protein, fibre, nitrogen-free extract and organic matter was significantly higher by offering wheat meal. The apparent digestibility of starch was not significantly influenced by the different starch sources.

Vplyv pšeničného a kukuričného škrobu na priebeh fermentácie v bachore, pasáž živín do dvanástnika a stráviteľnosť živín

Cieľom experimentu bolo zistiť vplyv skrmovania rôznych zdrojov škrobu na priebeh fermentačných procesov v bachore, pasáž živín do dvanástnika a zdanlivú stráviteľnosť živín. Základ kŕmnych dávok tvorila kukuričná siláž a ďatelinové seno, ku ktorým sme pridávali pšeničný šrot vo variante W a kukuričný šrot vo variante M. Experiment sme realizovali na štyroch čiernostrakatých býkoch s priemernou živou hmotnosťou 525 kg. Pokusné zvieratá boli kŕmené dvakrát denne o 6,30 a 18,30 hodine. Býci boli ošetrení bachorovou fistulou a dvanástnikovou T-kanylou. Za účelom zisťovania pasáže živín do dvanástnika bol použitý indikátor Cr_2O_3. Pomer škrobu k vláknine bol v kŕmnych dávkach 2,1:1 a percentuálny podiel vlákniny zo sušiny kŕmnych dávok predstavoval 17 %. Dvanástnikový chýmus sa odoberal v dvojhodinových intervaloch. Kvalitatívny zdroj škrobu ovplyvnil priebeh fermentačných procesov v bachore signifikantne. Koncentrácia kyseliny propiónovej, maslovej a mliečnej bola vyššia, keď sa skrmoval pšeničný šrot. Keď bol ako zdroj škrobu použitý kukuričný šrot, zaznamenali sme preukazne vyššiu pasáž tuku, vlákniny, bezdusíkatých látok výťažkových a škrobu do dvanástnika. V experimente sme nezaznamenali signifikantné rozdiely v pasáži dusíkatých látok do dvanástnika vplyvom skrmovania rôznych zdrojov škrobu. Pasáž dusíkatých látok do dvanástnika bola v porovnaní s ich príjmom o 33 % vyššia pri skrmovaní pšeničného šrotu a o 42 % vyššia pri skrmovaní kukuričného šrotu. Zdanlivá stráviteľnosť sušiny (76 ± 2 %), dusíkatých látok (67 ± 0,9 %), vlákniny (64 ± 1,9 %), bezdusíkatých látok výťažkových (82 ± 1,5 %) a organickej hmoty (76 ± 1,3 %) bola signifikantne vyššia pri skrmovaní pšeničného šrotu.

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