Journal of Animal and Feed Sciences, 16, Suppl. 2, 2007, 525–530

Effects of processing maize grains and soyabean on rumen fermentation and development of Holstein bull calves*

Y.Q. Zhang, X.Z. Deng, Z.M. Zhou, L.P. Ren and Q.X. Meng[1]

State Key Laboratory of Animal Nutrition, Beef Cattle Research Center and College of Animal Science and Technology, China Agricultural University Beijing 100094, P.R. China

ABSTRACT

A feeding trial using 12 Holstein bull calves (21±3 d) was conducted to investigate the effect of different processed maize grain and full fat soyabean included in the starter diets on their rumen fermentation and development. Three treatment starter diets contained different processed maize grain and soyabean: steam-flaked maize and soyabean (SFMS), extruded maize and soyabean (EMS), and ground maize and raw soyabean (GMS). During 10-week trial, total rumen VFA concentration tended to be influenced by different processing methods at wk 6 and 9 ($P<0.10$). The molar proportion of butyrate for calves receiving SFMS starter diets was higher than that of EMS and GMS starter diets ($P<0.05$) at wk 5 and 11. Rumen papillae development characteristics expressed by papilla length, papilla width and rumen wall thickness were remarkably different among treatment starter diets ($P<0.05$).

KEY WORDS: calves, processing, maize grain, full fat soyabean, rumen development

INTRODUCTION

Volatile fatty acids (VFA), primarily butyrate, are necessary to initiate the stomach modifications that change the calf from essentially a monogastric animal to a ruminating animal (Tamate et al., 1962). Previous studies indicated that grain processing level influenced rumen VFA production, rumen pH, and papillae development; however, the results were not always identical (Murphy et al., 1994; Lesmeister and Heinrichs, 2004). Most maize processing studies have been conducted utilizing mature ruminants, and extrapolation of these results to immature ruminants may be limited due to known

* Supported by The 948 Grand from Ministry of Agriculture of China, Project No. 2003-Z77
[1] Corresponding author: e-mail: qxmeng@cau.edu.cn

differences in digestion kinetics, microbial populations, and rumen capacity (Lesmeister and Heinrichs, 2004). Fewer data were available concerning the processing of grains and protein ingredients influencing development of ruminal function in calves. Therefore, this study was conducted to determine the effect of different processed maize grain and soyabean on rumen development of Holstein calves.

MATERIAL AND METHODS

Twelve Holstein bull calves (21±3 d) were assigned randomly to one of three groups and fed with fresh milk and calf starter pellets (pellet diameter = 0.7 cm), which were commercially formulated and contained steam-flaked maize and full fat soyabean (SFMS), extruded maize and full fat soyabean (EMS), or roughly ground maize and full fat soyabean (GMS) (Table 1). Ruminal fluid samples (100 ml) were collected before morning feeding *via* a stomach tube at 4, 5, 6, 7, 9, 11

Table 1. Ingredients and chemical compositions of three calf starters

Ingredient, %DM	SFMS[1]	EMS	GMS	Composition	SFMS	EMS	GMS
Steam flaked maize	45.5			DM, %	90.20	89.26	91.14
Extruded maize		45.5		TDN[5]	79.74	78.46	78.30
Ground maize			45.5	CP	21.05	21.45	18.87
Full fat soyabean (FFS)			7.3	Starch	38.08	38.45	42.33
Steam flaked FFS	7.3			EE	3.88	5.03	3.39
Extruded FFS		7.3		NDF	32.54	32.44	34.98
DDGS[2]	16.0	16.0	16.0	ADF	18.25	18.14	20.24
Mixed fibre [3]	5.5	5.5	5.5	Ca	1.21	1.33	1.20
Dry brewer's grain	14.0	14.0	14.0	P	0.67	0.67	0.62
Cottonseed meal	6.5	6.5	6.5				
Premix[4]	5.2	5.2	5.2				

[1] SFMS: steam-flaked maize and full fat soyabean, EMS - extruded maize and full fat soyabean, GMS - roughly ground maize and full fat soyabean; [2] DDGS - dehydrated distillers grains (maize) with solubles [3]mixed fibre contains, %: soyabean hulls 54.5, wheat bran 18.2, apple pulp 27.3; [4] Premix contains, %: fine limestone 28.9, dicalcium phosphate 21.2, salt 15.4, trace mineral mixture 13.5, vitamin mixture 1.3, Diamond V "XP" 9, magnesium oxide 7.7, Dynamate 3.0; [5]calculated from tabulated value (NRC, Nutrient Requirements of Dairy Cattle, 2001. 7th Edition. National Academy Press)

and 13 weeks of age. Ruminal pH was determined immediately using a pH-meter and ruminal VFA was analysed (Ervin et al., 1961). Calves were euthanized at 13 wk of age. Rumen tissue samples were collected from five sampling points in the rumen, including part A, left B (LB), left C (LC), left D (LD) and left E (LE), and analysed papillae length (PL), papillae width (PW), and rumen wall thickness (RWT) according to Lesmeister et al. (2004). The epidermis of papillae in part A of the rumen was morphometricly measured using the scanning electron microscopy (McGavin and

Morrill, 1976). Data were analysed as a completely randomized design and two-way analysis of variance was conducted using the GLM procedure of SAS (1999).

RESULTS

Table 2 showed the results of rumen fermentation characteristics of three treatments. Rumen pH varied from 6.36 to 7.53 and was not affected by the treatment diet (P>0.21) but by age (P<0.001). Rumen pH values increased with calf age and were significantly higher at wk 11 and 13 than those at wk 5, 6 and 7 (P<0.05), respectively.

Table 2. Effects of treatment starter diets on rumen fermentation characteristics[1]

Item	Age[2]	SFMS	EMS	GMS	SEM	P	Item	Age	SFMS	EMS	GMS	SEM	P
pH	4	7.01	6.78	7.14	0.22	0.42	Propionate	4	24.04	27.31	25.04	4.76	0.86
	5	6.54	6.50	6.80	0.36	0.77	mol%	5	33.93	33.92	26.75	3.58	0.25
	6	7.02	6.66	6.92	0.30	0.69		6	25.72	27.30	28.78	3.40	0.75
	7	6.36	7.00	6.76	0.24	0.21		7	22.35	26.68	24.17	1.85	0.27
	9	7.00	7.10	7.17	0.19	0.83		9	31.18	28.51	25.09	1.67	0.11
	11	7.49	7.33	7.41	0.09	0.48		11	25.32	28.69	31.96	2.60	0.18
	13	7.30	7.43	7.53	0.90	0.14		13	25.15	25.23	22.96	1.22	0.35
Total VFA	4	26.84	32.30	29.04	5.27	0.73	Butyrate	4	5.09	3.89	4.34	0.66	0.45
mmol/l	5	33.27	29.74	26.00	2.49	0.15	mol%	5	6.67^{a}	4.65^{b}	5.25^{b}	0.38	0.02
	6	32.85	26.86	41.19	5.45	0.09		6	7.48	10.21	6.60	1.37	0.18
	7	42.18	46.42	41.52	3.70	0.58		7	12.14	11.06	8.93	1.96	0.53
	9	59.76	43.63	47.04	4.10	0.05		9	9.94	9.42	9.89	1.71	0.97
	11	49.75	48.54	43.68	6.72	0.80		11	15.51^{a}	10.99^{ab}	6.69^{b}	2.18	0.03
	13	52.50	56.37	40.46	10.86	0.51		13	9.54	11.06	12.83	1.98	0.49
Acetate	4	62.24	64.14	64.75	3.63	0.88	Isobutyrate	4	2.96	1.40	1.88	0.36	0.07
mol%	5	52.09	57.07	61.77	3.10	0.11	mol%	5	1.37	0.85	1.70	0.49	0.47
	6	60.17	55.71	57.21	4.20	0.69		6	1.68^{a}	0.99^{b}	1.60^{a}	0.21	0.07
	7	58.14	55.83	59.51	3.10	0.67		7	1.26	1.02	1.69	0.21	0.13
	9	53.38	53.70	58.59	1.63	0.11		9	1.11	1.07	1.41	0.12	0.17
	11	51.72	52.93	54.99	3.45	0.75		11	1.46^{a}	0.84^{b}	1.52^{a}	0.09	0.001
	13	58.96	57.25	56.73	2.39	0.75		13	1.30^{ab}	1.11^{b}	1.63^{a}	0.13	0.05

[1] means with different superscripts in the same line differ significantly (P<0.05); [2] age is expressed as week

Total rumen VFA concentrations were unaffected by treatment starter diets (P>0.05), but affected by the age of calves in this study (P<0.001). However, total rumen VFA of calves receiving GMS starter tended to be higher than EMS and SFMS (P=0.089) diets at wk 6, and higher for SFMS diets than EMS and GMS (P=0.051) at wk 9. The molar proportions of acetate and propionate were not affected by dietary treatments (P>0.05). However, the molar proportion of acetate was significantly lower at wk 4 than at wk 11 and 13 (P<0.05), whereas propionate was higher at wk 5 than at wk 13 (P<0.05). Finally, the molar proportion of butyrate was not affected

by the treatment diets except wk 5 and wk 11, but significantly affected by age (P<0.05). At wk 5 and wk 11, the molar proportions were higher for calves receiving the SFMS diet than the EMS and GMS diets, respectively. The molar proportion of butyrate was higher at wk 7, 9, 11, and 13 than at wk 4 and 5 (P<0.001). As to the molar proportions of isobutyrate, no difference was found among treatment starter diets except for wk 6, 11, and 13. The molar proportion of isobutyrate for the calf receiving GMS diets was lower than the SFMS and EMS diets (P<0.05) at wk 6, 11 and 13 declining with increased age of calves (P<0.05).

The results of rumen development characteristics expressed by papilla length, papilla width and rumen wall thickness as affected by different mechanical processing are presented in Table 3. Papillae at part A, LC, LD, and LE were longer in calves receiving SFMS starter than EMS and GMS diets (P<0.05); however, PL at part A was not influenced by treatment starter diets (P>0.05). PW was not affected by treatment starter diets except for part E, which was wider for SFMS diets than GMS diets (P=0.041). The RWT of calves receiving the GMS diet was greater than the EMS and SFMS diets at part A and part LE (P<0.05). Photomicrograph of rumen papillae and their keratinized epidermis in part A of the rumen tissue from three treatment starter diets are illustrated in Figure 1. The upper micrographs (a) showed that papillae from the calves receiving the SFMS diet were obviously longer than GMS and EMS diets. Ruminal papillate epidermis from calves fed on three treatment starter diets was moderately keratinized; however, many inerratic crystals were observed on the papillate epidermis from calves receiving the GMS diet.

Table 3. Rumen development measurements of Holstein calves receiving different starter diets[1]

Item	SFMS	EMS	GMS	SEM	P
	cm				
PL_A	1.05[a]	0.79[b]	0.72[b]	0.040	0.003
PW_A	0.34	0.42	0.34	0.041	0.319
RWT_A	1.11[b]	0.89[b]	1.57[a]	0.124	0.021
PL_{LB}	0.60	0.46	0.58	0.098	0.557
PW_{LB}	0.30	0.32	0.38	0.063	0.666
RWT_{LB}	1.58	1.59	1.29	0.212	0.548
PL_{LC}	0.57[a]	0.47[b]	0.45[b]	0.020	0.009
PW_{LC}	0.36	0.43	0.36	0.073	0.769
RWT_{LC}	1.98	1.75	1.98	0.268	0.790
PL_{LD}	1.24[a]	0.92[b]	0.60[c]	0.098	0.007
PW_{LD}	0.44	0.44	0.32	0.059	0.331
RWT_{LD}	1.20	1.40	0.97	0.161	0.240
PL_{LE}	1.24[a]	0.87[b]	0.74[c]	0.028	<0.001
PW_{LE}	0.52[a]	0.46[ab]	0.41[b]	0.022	0.041
RWT_{LE}	1.19[c]	1.47[b]	1.72[a]	0.055	0.002

[1] means with different superscripts in the same line differ significantly (P<0.05). PL, PW, and RWT are short for papilla length, papilla width, and rumen wall thickness. The subscripts of A, LB, LC, LD, and LE mean the data of which sampling points in the rumen

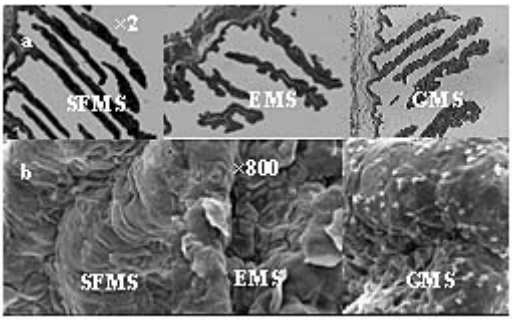

Figure 1. Photomicrograph of papilla from part A rumen tissues taken from calves fed on three treatment starter diets: (a) dissecting micrograph of papilla (×2), (b) scanning electron micrograph of papillate epidermis (×800)

DISCUSSION

The rumen pH observed in this experiment was in line with the report of Murdock and Wallenius (1980), but quite higher than the result of Lesmeister and Heinrichs (2004). The different sampling time points and methods (through stomach tubes or rumen cannulae) might cause this difference. The pH results among treatment starter diets in the current study were inconsistent with the previous study (Lesmeister and Heinrichs, 2004). The ruminal pH values increased with age of calves, indicating an increased absorption of VFA occurring in the rumen as a consequence of more developed and matured rumen (Suárez et al., 2006). Total rumen VFA results differed from the observation of Lesmeister and Heinrichs (2004), which could be explained by the forage offered in this study. Total rumen VFA concentrations of SFMS starter diets were higher at wk 9, which might be attributed to the higher energy density and digestibility of SFMS diets. The results of the molar proportion of acetate and propionate differed from the observation of Lesmeister and Heinrichs (2004), which could be explained by the different method of rumen fluid sampling and the dietary forage incorporation between the studies. From the results of ruminal butyrate molar proportion in this study, feeding SFMS starter diets seemed to affect ruminal butyrate concentrations in neonatal calves, suggesting a profit obtained from the steam flaking method to process maize grains and full fat soyabean included in the starter diets of the calves.

Rumen papillae at part A, LC, LD, and LE were longer in calves receiving SFMS starter diets than EMS and GMS starter diets. Similar results were reported by Lesmeister and Heinrichs (2004). Higher molar proportion of butyrate in ruminal contents of calves fed SFMS diets and their higher dietary energy density might explain the longer PL for the SFMS starter diets. Feeding SFMS starter diets resulted in an increased rumen PL and PW, indicating increased rumen absorptive surface areas occurring in calves fed steam flaked maize and soyabean starter diets. The diets containing GMS generally have fine feed particles, which may be trapped on the rumen papillae, causing a difficulty in

removing sloughed epithelial cells and subsequently resulting in keratin buildup and rumen mucosa thickening (Beharka et al., 1998). This explanation especially covers the observation about the greater RWT for calves receiving GMS starter diets at part A and part E. However, there was a moderate keratinized epidermis of papillae from calves fed all three treatment starter diets, indicating appropriate particle sizes of all three starter diets used in the current study. The interesting crystals on the surface of papillae from calves receiving GMS were out of our knowledge. Therefore, a further study is needed to be done in the next step.

CONCLUSIONS

Feeding steam-flaked maize and soyabean starter diets to the Holstein bull calves did not affect their total rumen VFA concentration and molar proportion of acetate and propionate. However, the molar proportion of butyrate was higher for calves receiving SFMS than extruded maize and soyabean and ground maize and soyabean at wk 5 and 11. Calves receiving SFMS starter diets had longer papillae in the rumen wall. Therefore, use of steam flaking method to process maize grains and soyabean might be advantageous in ruminal development and neonatal calf growth.

REFERENCES

Beharka A.A., Nagaraia T.G., Morrill J.L., Kennedy G.A., Klemm R.D., 1998. Effects of form of the diet on anatomical, microbial and fermentative development of the rumen of neonatal calves. J. Dairy Sci. 81, 1946-1955

Erwin E.S., Marco G.J., Emery E.M., 1961. Volatile fatty acid analyses of blood and rumen fluid by gas chromatography. J. Dairy Sci. 44, 1768-1771

Lesmeister K.E., Heinrichs A.J., 2004. Effects of maize processing on growth characteristics, rumen development, and rumen parameters in neonatal dairy calves. J. Dairy Sci. 87, 3439-3450

Lesmeister K.E., Tozer P.R., Heinrichs A.J., 2004. Development and analysis of a rumen tissue sampling procedure. J. Dairy Sci. 87, 1336-1344

McGavin M.D., Morrill J.L., 1976. Scanning electron microscopy of ruminal papillae in calves fed various amount and forms of roughage. Amer. J. Vet. Res. 37, 497-508

Murdock F.R., Wallenius R.W., 1980. Fiber sources for complete calf starter ration. J. Dairy Sci. 63, 1869-1873

Murphy T.A., Fluharty G.L., Loerch S.C., 1994. The influence of intake level and maize processing on digestibility and ruminal metabolism in steers fed all-concentrate diets. J. Anim. Sci. 72, 1608-1615

SAS, 1996. SAS System for Windows, Release 6.12, SAS Institute Inc. Cary, NC

Suárez B.J., Van Reenen C.G., Beldman G., van Delen J., Dijkstra J., Gerrits W.J.J., 2006. Effects of supplementing concentrates differing in carbohydrate composition in veal calf diets: I. Animal performance and rumen fermentation characteristics. J. Dairy Sci. 89, 4365-4375

Tamate H., McGilliard A.D., Jacobson N.L., Getty R., 1962. Effect of various dietaries on the anatomical development of the stomach in the calf. J. Dairy Sci. 45, 408-420