Sodium Bicarbonate and Yeast Culture Effects on Ruminal Fermentation, Growth, and Intake in Dairy Calves

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ABSTRACT

Sodium bicarbonate and yeast culture effects on ruminal fermentation, intake, and growth were evaluated in young calves. In trial 1, nine ruminally cannulated Holstein calves averaging 12 wk of age were fed control starter (17% CP) or starters containing 3% sodium bicarbonate or .2% yeast (*Saccharomyces cerevisiae*) culture in a 3 × 3 Latin square. Calves were fed for ad libitum consumption for 10 d and then at 85% of ad libitum intake to d 14. Ruminal fluid taken at 0 h postfeeding tended to have higher pH and a greater proportion of acetate when calves were fed sodium bicarbonate, but other ruminal and blood parameters did not differ among treatments. By 4 h after feeding, ruminal VFA had increased to 120.7 m*M*, molar proportions of individual acids were altered, and blood ketones and VFA increased in treated calves. In trial 2, 42 Jersey calves were fed experimental starters for ad libitum consumption during a 12-wk study. Calves began the study at 3 to 5 d of age. There were no significant effects of yeast culture or sodium bicarbonate on DMI or intake of starter, rates of gain, or feed efficiency. Plasma urea N was reduced when sodium bicarbonate was fed. Both sodium bicarbonate and yeast culture affected blood and ruminal metabolites when calves were limit-fed but did not influence intake or daily gain when calves were fed for ad libitum consumption.
(**Key words**: calves, sodium bicarbonate, yeast culture, rumen)

Abbreviation key: **ACAC** = acetoacetate, **BC** = 3% sodium bicarbonate in starter, **BHB** = β-hydroxybutyrate, **CON** = control calf starter, **Y** = .2% yeast culture in starter.

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INTRODUCTION

Management strategies to reduce the age at which young calves are weaned can reduce rearing costs, morbidity, and mortality. However, early intake of high grain diets may be associated with low ruminal pH, increased concentration of ruminal VFA and lactic acid, and, possibly, ruminal parakeratosis (1, 2, 6). Sodium bicarbonate has been included in calf diets to help to maintain ruminal pH and to alleviate depressions in intake associated with ruminal hyperacidity (7, 16, 19). However, responses to ruminal buffers depend on diet composition; calves fed diets that ferment rapidly in the rumen often receive the greatest benefit.

Recently, fungal (*Aspergillus oryzae*) or yeast (*Saccharomyces cerevisiae*) cultures fed to cattle have been shown to alter ruminal fermentation (15, 20) and to improve ruminal (14, 28) and total tract (14, 27) digestibilities of CP and fiber. Others, however, have reported no significant effect on digestibility (3, 11) or on intake and milk production (3, 10). Effects of microbial additives in diets of young calves have been equivocal. Behraka et al. (5) reported earlier weaning and increased ruminal microbial activity when *A. oryzae* was fed, whereas Wagner et al. (26) reported no effect of yeast culture on ruminal fermentation or growth of young calves. Williams et al. (28) reported increased ruminal pH in adult dairy cattle fed yeast culture; the increase was attributed to reduced concentration of ruminal L(+)-lactate. Nisbet and Martin (22) recently reported that growth of *Selenomonas ruminantium* in vitro was improved by inclusion of *Sacch. cerevisiae* culture when lactate was used as substrate. They (22) suggested that yeast culture may provide growth factors for lactate utilizers, thereby reducing concentration of lactate. Because low ruminal pH and high

TABLE 1. Formulation of experimental starters.[1]

Item	CON	BC	Y
	(%, as fed)		
Corn, no. 2 ground	27.32	29.02	28.10
Soybean meal (48% CP)	15.00	15.13	15.00
Soybean hulls	21.00	18.00	20.00
Wheat middlings	26.00	26.00	26.00
Animal fat	1.00	1.00	1.00
Molasses	5.00	3.10	5.00
Additives[2,3]	4.68	4.74	4.69
Yeast culture	0	0	.2
Sodium bicarbonate	0	3.0	0

[1]CON = Control calf starter, BC = 3% sodium bicarbonate, Y = .2% yeast culture.

[2]Included salt, limestone, dicalcium carbonate, dynamate, nonnutritive binder, and vitamin and mineral premix.

[3]To contain a minimum of 50 ppm of Fe, .10 ppm of Co, 10 ppm of Cu, 40 ppm of Mn, 40 ppm of Zn, 25 ppm of I, .2 ppm of Se, 2200 IU of vitamin A/kg, 300 IU of vitamin D/kg, and 25 IU of vitamin E/kg.

concentrations of ruminal lactate may be a problem in young calves, our objective was to measure the effects of yeast culture and sodium bicarbonate on ruminal fermentation and performance of young calves fed high grain diets.

MATERIALS AND METHODS

Experiment 1

Calf Assignments and Design. Nine weaned Holstein bull calves averaging 12 (SE = .5) wk of age were assigned randomly to one of three treatments in a replicated 3 × 3 Latin square. Calves were previously ruminally cannulated at 1 to 2 wk of age and weaned at 4 wk of age. Treatments were control calf starter (**CON**), calf starter with 3% sodium bicarbonate (**BC**; Church & Dwight, Inc., Princeton, NJ), or calf starter with .2% yeast culture (**Y**; Alltech Inc., Nicholasville, KY). Diets (Table 1) were formulated to be isocaloric and isonitrogenous. Starters were offered once daily for ad libitum consumption from 0 to 10 d of each period. From d 11 to 14, starter was restricted to approximately 85% of ad libitum consumption to minimize refusals. On d 14, feed offered was switched after the 4-h sampling. Calves were housed individually in 1.2 × 4.8-m pens bedded with shavings. Water was available at all times.

Sampling and Data Collection. Calves were weighed at the initiation of the study and at the end of each 14-d period. Jugular blood (approximately 10 ml) was taken from calves on d 14 of each period at 0 and 4 h after the a.m. feeding into evacuated containers. A 2-ml subsample was deproteinated immediately in 2 ml of 1 *M* perchloric acid for analysis of β-hydroxybutyrate (**BHB**) and acetoacetate (**ACAC**) by the method of Williamson and Mellanby (29). A second sample was deproteinated in 4 ml of 8% perchloric acid prior to analysis of L(+)-lactate (lactate kit 826; Sigma Chemical Co., St. Louis, MO). Remaining blood was added to 400 μl of 6% EDTA prior to separation of plasma, analysis of VFA (24), NEFA (Wako-C kit; Wako Pure Chemicals, Osaka, Japan), and glucose (glucose kit 510; Sigma Chemical Co.). Deproteinated blood was analyzed immediately for BHB and ACAC. Plasma was stored (–20°C) until analyzed.

Ruminal fluid was collected by vacuum pump from the ruminal cannula immediately after blood was sampled. Ruminal pH was measured, and fluid was quickly frozen in liquid N. Frozen fluid was stored (–20°C) until it was analyzed for VFA by gas chromatography and NH_3 N, using a commercial urea N kit (urea kit 610; Sigma Chemical Co.) with exclusion of urease and use of ammonium chloride standards. Lactic acid [D(–)- and L(+)-isomers] was analyzed using the appropriate lactate dehydrogenase and lactic acid standards. Samples of calf starter and milk replacer were taken daily and composited by period for analysis of DM, CP (4), ADF, NDF (13), and minerals.

Statistical Analysis. Data were analyzed as a Latin square experimental design; ruminal, blood, and intake measurements were dependent variables; and square, period within square, treatment, and animal within square were independent variables. Single degree of freedom contrasts compared BC and Y treatments against CON.

Experiment 2

Calf Assignments and Design. Jersey heifer and bull calves (n = 42) were assigned ran-

TABLE 2. Chemical composition of feeds used.[1]

Item	CON		BC		Y	
Experiment 1	(%)					
	$\bar{X}$	SE	$\bar{X}$	SE	$\bar{X}$	SE
DM	87.4	.4	86.8	.5	87.4	.5
	(% of DM)					
CP	16.9	.9	16.4	.5	15.8	.7
ADF	15.3	.7	14.3	.4	15.5	.4
NDF	30.7	.6	32.0	1.2	31.7	1.0
	(mg/g of DM)					
Ca	18.4	1.7	17.3	.7	18.7	2.0
P	5.5	.2	5.5	.1	5.1	.1
Mg	3.5	.1	3.5	.1	3.6	.1
K	11.7	.6	13.0	1.1	12.1	.7
Experiment 2	(%)					
DM	89.8	.8	89.7	.8	89.9	.9
	(% of DM)					
CP	17.9	.7	17.9	.4	18.6	.7
ADF	14.9	.6	12.5	.6	13.6	.5
NDF	30.1	.9	26.4	.9	29.6	1.2
	(mg/g of DM)					
Ca	11.7	.8	13.2	.8	13.0	.8
P	6.5	.6	7.0	.3	7.0	.5
Mg	3.6	.3	3.2	.3	3.4	.2
K	13.9	.7	12.6	.6	14.2	.7

[1]CON = Control calf starter, BC = 3% sodium bicarbonate, Y = .2% yeast culture; n = 4.

domly at birth to treatments in Experiment 1. Calves were left with the dam for 3 d and then moved to individual pens for the duration of the experiment. Commercial milk replacer was fed twice daily at 1.4 kg per feeding for 35 d; thereafter milk was fed once daily and reduced by 50% of the previous day's feeding to weaning at 42 d. Starter was fed once daily from d 1 for ad libitum consumption, and feed refusals were measured once daily. Water was available at all times.

Sampling and Data Collection. Calves were weighed as they began the study and every 14 d thereafter to d 84. Samples of calf starter and milk replacer were taken once every 14 d and pooled monthly for analysis of DM, CP, ADF, NDF, and minerals. Jugular blood (approximately 10 ml) was taken from calves every 14 d at 0 and 4 h after the a.m. feeding into evacuated containers as described previously. Blood was shipped to the laboratory and stored (–20°C) prior to analysis for L(+)-lactate, NEFA, glucose, and plasma urea N.

Statistical Analysis. Data were analyzed as a split-plot experimental design using 7-d (intake) or 14-d (BW, daily gain, feed efficiency, plasma metabolites) measurements as dependent variables and treatment, animal within treatment, week of study, and week × treatment as independent variables in the model. Animal within treatment was used as the error term to test treatment. Significance of $P < .05$ was used unless otherwise noted.

RESULTS AND DISCUSSION

Experiment 1

Calves were healthy throughout the study. One calf was removed from the study in period 1 because of cannula failure and was replaced in periods 2 and 3. Data from period 1 were omitted from analysis. Other calves were healthy with only minor incidence of disease. Crude protein in Y was somewhat lower than in other treatments (Table 2) although the difference was not significant.

Mean BW and average daily gain were unaffected by treatment and averaged 95.6 and .89, 96.2 and .88, and 93.5 and .80 kg in

calves fed CON, BC, and Y, respectively. Increases in BW indicated that, although intake of calves was restricted during the last 4 d of each period, gain was not impaired markedly.

Intake of DM compared favorably with NRC (21) recommendations during the ad libitum feeding period, although DMI was reduced ($P < .01$) when calves were fed Y. Average DMI from 1 to 10 d were 3.2, 3.3, and 2.8 kg/d for calves fed CON, BC, and Y, respectively.

Concentration of selected blood and ruminal metabolites are in Table 3. Generally, treatments had few among-treatment effects at 0 h postfeeding. Plasma propionate tended to be lower in calves fed BC ($P < .10$). Prefeeding metabolite concentrations were within expected ranges for calves consuming high grain diets, except urea N was relatively high for all treatments and averaged 8.8 mg/dl. Similar urea N concentrations in calves fed 17% CP diets have been reported (7). Concentrations of L(+)-lactate averaged 1.67 to 3.15 m*M* at 0 h postfeeding, and they were similar to other reported blood concentrations (12).

Ruminal pH at 0 h postfeeding tended to be higher when calves were fed BC than when they were fed CON ($P < .10$). The ruminal pH of calves fed Y did not differ from that of calves fed CON. Alleviation of depressed ruminal pH in cattle fed sodium bicarbonate has been documented (9), and this finding was expected. However, the ability of yeast culture to affect ruminal pH has not been reported consistently (8, 28). Also, molar percentage of acetate tended to be higher ($P < .10$) at the expense of propionate when BC was fed. No effects because of Y on ruminal or blood parameters were significant at 0 h.

By 4 postfeeding, concentrations of most ruminal and blood metabolites had changed markedly (Table 3). Feeding caused a decline in ruminal pH, an increase in concentration of ruminal VFA, and a shift in fermentation products. Although the change in pH from 0 to 4 h did not differ among treatments, pH at 4 h was higher when calves were fed BC than when they were fed other treatments. Sodium bicarbonate was efficacious in assisting maintenance of ruminal pH when calves consumed high grain diets, particularly after feeding, when reduced ruminal pH was expected.

Total ruminal VFA concentration increased with feeding (Table 3) from 71.9 to 120.7 m*M* without effect of treatment. The rapid increase in concentration of VFA with feeding is consistent with fermentation of nonstructural carbohydrate by ruminal bacteria. With feeding, changes in molar proportions of VFA were observed, particularly when calves were fed Y, which increased ruminal acetate and butyrate and reduced propionate. When calves were fed BC, the proportion of ruminal acetate declined and was similar to that of calves fed CON at 4 h. Butyrate was increased with feeding and was higher at 4 h in calves fed BC. Calves fed CON exhibited little change in ratios of VFA, although total VFA concentration increased by nearly 49 m*M* at 4 h.

Concentration of ruminal lactate increased at 4 h (Table 3) for all treatments and ranged from 6.64 to 13.03 m*M*. Contribution of each isomer to total lactate was approximately 50%. These concentrations are higher than those of other reports in young, weaned calves (1, 2) but are similar to those of cattle fed high grain diets (12, 18, 28). Increases in L(+)- and D(−)-lactate were reduced by 42 and 25%, respectively, when calves were fed Y. However, because of large standard errors associated with lactate at 4 h, differences from control were not significant. Increases in lactate concentration by 4 h after feeding (3.3 to 9.2 m*M*) indicate that fermentation had shifted toward lactate production and that lactate producers had begun to predominate by 4 h (18). Reduction in concentration of lactate when yeast culture was fed has been reported (28) in steers fed rations containing 50:50 or 60:40 concentrate to forage, but particularly in the higher concentrate diet. Nisbet and Martin (22) recently hypothesized that large amounts of L-malic acid measured in yeast culture may stimulate growth of lactate utilizers such as *Sel. ruminantium*, thereby reducing ruminal lactate concentration. Our data suggest that the effect may be similar on all-grain diets.

Concentrations of most blood metabolites changed markedly in response to feed intake and ruminal fermentation. Concentration of blood ketones increased when calves were fed BC and Y. Consequently, 4-h concentrations of BHB and ACAC differed ($P < .01$ and $P < .05$, respectively) from those of calves fed CON. Similar increases in blood ketones have been reported previously (23, 25). The increased ruminal butyrate (Table 3) observed when calves were fed BC and Y likely was at

TABLE 3. Concentration of selected blood and ruminal metabolites in calves fed control starter (CON) or starter containing 3% sodium bicarbonate (BC) or .2% yeast culture (Y).

Item	0 h[1]				4 h				Change			
	CON	BC	Y	SE	CON	BC	Y	SE	CON	BC	Y	SE
Rumen												
pH	6.04	6.47[a]	6.41	.15	5.08	5.46[b]	5.08	.09	−.97	−1.02	−1.33	.17
NH_3 N, mg/dl	15.7	14.3	16.1	2.7	17.2	10.7	19.2	3.9	1.49	−3.63	3.10	3.50
L(+)-Lactate, m*M*	3.65	3.86	3.08	.60	9.85	12.70	6.65	1.50	6.20	8.84	3.57	1.90
D(−)-Lactate, m*M*	4.10	3.86	3.32	.33	8.47	13.03[a]	6.64	1.60	4.38	9.17	3.32	1.90
VFA, m*M*	80.0	67.9	70.5	5.8	128.5	113.6	132.0	9.5	48.5	45.6	61.5	8.5
Acetate, mol/100 mol	56.6	60.1[a]	57.0	1.2	56.8	58.7	61.4[c]	1.0	.2	−1.5	4.4[a]	1.4
Propionate, mol/100 mol	27.3	22.3	26.5	2.0	27.1	22.3[b]	19.8[c]	1.4	−.1	.0	−6.7[b]	1.8
Butyrate, mol/100 mol	9.3	9.8	9.2	1.0	10.3	13.7[a]	13.2[a]	1.1	1.1	3.9[b]	4.0[b]	.8
Isobutyrate, mol/100 mol	1.2	1.8	1.6	.2	.2	.4	.2	.1	−1.0	−1.4	−1.4	.4
Valerate, mol/100 mol	4.2	4.1	4.0	.1	5.0	4.5	4.8	.2	.8	.4	.8	.3
Isovalerate, mol/100 mol	1.4	1.9	1.6	.2	.5	.5	.5	.1	−.9	−1.5	−1.0	.3
Blood and plasma												
BHB,[2] m*M*	.438	.481	.538	.06	.572	1.204[c]	1.192[c]	.130	.179	.723[b]	.673[b]	.150
ACAC,[3] m*M*	.007	.006	.005	.001	.006	.021[b]	.019[b]	.005	−.005	.015[b]	.015[b]	.005
L(+)-Lactate, m*M*	2.44	1.67	3.15	.50	1.70	1.66	1.50	.15	−.08	−.01	−1.37[a]	.40
NEFA, m*M*	.26	.22	.27	.04	.14	.10	.11	.01	−.15	−.14	−.16	.06
Glucose, m*M*	4.47	4.18	4.65	.32	4.28	4.68	4.08	.19	−.26	.50[a]	−.61	.24
Urea N, mg/dl	9.95	8.58	7.97	.80	9.29	7.06	7.90	.85	−.46	−1.09	−.14	.45
VFA, m*M*	.71	.65	.73	.06	.78	.86	.85	.04	.04	.19	.11	.08
Acetate, mol/100 mol	97.3	97.6	97.3	.2	94.1	95.7[b]	95.6[b]	.5	−3.3	−1.9[a]	−1.7[a]	.5
Propionate, mol/100 mol	2.3	2.0[a]	2.3	.1	4.3	2.9[a]	3.0[a]	.4	2.0	.8[a]	.7	.4
Butyrate, mol/100 mol	.4	.4	.4	.2	1.6	1.5	1.4	.1	1.3	1.1	1.0[a]	.1

[a]Differs from control ($P < .10$).

[b]Differs from control ($P < .05$).

[c]Differs from control ($P < .01$).

[1]Hour after feeding.

[2]β-Hydroxybutyrate.

[3]Acetoacetate.

least partially responsible for increased blood ketones. Why ketone concentration did not increase when calves were fed CON is not clear. However, plasma VFA did not increase markedly when calves were fed CON rather than BC or Y (Table 3).

Plasma urea N concentrations (Table 3) were not significantly lower when calves were fed BC or Y at 4 h. Hart and Polan (16) reported that sodium bicarbonate reduced plasma urea N without effect on rate of gain or N balance. Also, Curnick et al. (7) reported that BC added to 17% CP diets improved N utilization without effect on plasma urea N concentration.

Plasma L(+)-lactate declined with feeding but tended to be lower when calves were fed Y ($P < .10$), which likely is a result of a smaller increase in ruminal lactate when Y was fed and, possibly, insulin secretion. Glucose increased with feeding when calves were fed BC, whereas concentration declined when Y and CON were fed. Plasma acetate was higher and butyrate lower than control in both Y and BC treatments at 4 h postfeeding.

Experiment 2

Numerous health problems occurred during the study. One calf died during the experiment and was not replaced. Thirty-three of the remaining 41 calves were treated for scours or respiratory infections; scours usually occurred during the first 2 wk of age and were presumed to be associated with enterotoxigenic *Escherichia coli*. Incidence of disease was unrelated to treatment, and calves were treated with oral antibiotic and electrolyte therapies as required. As a result of the high incidence of disease, rate of gain during the first few weeks of the study was poor; average daily gain during the first 4 wk was 117 g/d. This is lower than published standards (17, 21), which range from 200 to 500 g/d for Jersey calves. However, after weaning (6 wk), calves gained well and averaged 446 g/d.

Chemical composition of starters used in this experiment varied from those used in Experiment 1 (Table 2). Crude protein and P of all starters were higher, and fiber fractions and Ca were lower, during Experiment 2. Starters were manufactured according to the same formulation, but differences in ingredient composition probably accounted for the observed differences.

No significant differences in intake, rate, or efficiency of gain were observed when BC or Y were fed (Table 4) over the 12-wk study or within preweaning and postweaning periods. Intake of DM was generally low until weaning and then increased to 1957 g/d by 12 wk.

Small responses to treatment in this experiment may have been caused by the relatively low intake of starter. Calves were fed starter for ad libitum consumption; therefore, intake probably was not limited to a short period as in Experiment 1. Others (16) have reported little effect of buffers on growth and intake in young calves, but Kellaway et al. (19) found

TABLE 4. Least squares means of BW, intake, daily gain, and feed efficiency in calves fed control starter (CON) or starter containing 3% sodium bicarbonate (BC) or .2% yeast culture (Y), Experiment 2.

Item	Treatment			SE
	CON	BC	Y	
BW, kg				
Initial	25.3	25.4	24.8	.7
Final[1]	52.9	53.9	53.5	1.3
wk 6[1]	32.6	32.5	32.7	.9
Daily gain, g/d				
wk 1 to 6	179	172	183	21
wk 7 to 12	484	513	488	26
wk 1 to 12	330	343	335	15
DMI, g/d				
Total				
wk 1 to 6	473.8	501.9	491.1	21.0
wk 7 to 12	1474.3	1522.9	1418.9	71.6
wk 1 to 12	974.1	1012.4	955.0	42.7
Starter				
wk 1 to 6	207.7	235.0	220.2	13.6
wk 7 to 12	1474.3	1522.9	1418.9	71.6
wk 1 to 12	841.0	879.0	819.6	42.9
Milk replacer				
wk 1 to 6	266.0	271.6	271.0	2.2
CP Intake, g/d				
wk 1 to 6	101.2	106.2	106.1	3.8
wk 7 to 12	263.9	272.6	263.9	12.9
wk 1 to 12	182.5	189.4	185.0	7.7
TDN Intake,[2] g/d				
wk 1 to 6	509.5	532.3	525.6	16.9
wk 7 to 12	1179.4	1218.3	1135.1	57.3
wk 1 to 12	844.4	875.3	830.4	34.2
Gain:feed				
wk 1 to 6	.295	.271	.298	.036
wk 7 to 12	.308	.321	.346	.023
wk 1 to 12	.301	.296	.322	.017

[1]Covariately adjusted for initial BW.

[2]Estimated from NRC (21).

TABLE 5. Least squares means (averaged across all weeks) of selected plasma metabolites taken 0 or 4 h after feeding in calves fed control starter (CON) or starter containing 3% sodium bicarbonate (BC) or .2% yeast culture (Y), Experiment 2.

Item	Treatment			SE
	CON	BC	Y	
L(+)-Lactate, m*M*				
0 h	.89	.90	.87	.03
4 h	1.00	.95	.94	.03
Glucose, m*M*				
0 h	4.24	4.40	4.10	.12
4 h	4.37	4.49	4.59	.12
NEFA, m*M*				
0 h	.197	.178	.192	.013
4 h	.123	.118	.131	.015
Urea N, mg/dl				
0 h	11.4	10.0[a]	11.8	.5
4 h	11.3	9.9[a]	11.8	.5

[a]Differs from control ($P < .05$).

that calves fed sodium bicarbonate consumed more feed, particularly after weaning. Curnick et al. (7) reported greater feed intake and rates of gain when 3% sodium bicarbonate was added to the diet. Although both additives may be useful in influencing the ruminal environment when calves are limit-fed, results of Experiment 2 suggest that effects of BC and Y in calves fed for ad libitum consumption may be limited. A lack of intake and growth response to yeast culture is consistent with findings of Wagner et al. (26) who fed yeast culture at .1% of the formulation.

Plasma metabolites (Table 5) were unaffected by treatment, except plasma urea N, which was reduced by feeding BC at both 0 and 4 h postfeeding. A significant week × treatment interaction indicated that most of the response to BC occurred after weaning at 6 wk. Mean plasma urea N concentrations for CON and BC treatments (averaged across 0- and 4-h sampling times) at 2, 4, 6, 8, 10, and 12 wk were 7.3, 7.8; 7.6, 7.4; 13.2, 11.9; 14.7, 12.1; 12.9, 10.0; and 12.8, 10.4 mg/dl, respectively.

CONCLUSIONS

Both Y and BC influenced ruminal and blood metabolites when calves were limit-fed. The BC was effective in maintaining ruminal pH and elevating blood glucose. The Y tended to limit the increase in ruminal D(−)- and L(+)-lactate but did not influence rate of gain or intake when calves were fed for ad libitum consumption.

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