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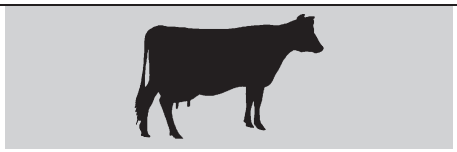

Effects of Supplementation of Natural Zeolite on Intake, Digestion, Ruminal Fermentation, and Lactational Performance of Dairy Cows[1]

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ABSTRACT

A lactating dairy cow experiment was conducted to determine the influence of a ruminal buffer product containing magnesium-exchanged zeolite on ruminal fermentation and lactational performance. The experimental TMR diet consisted of 38% alfalfa hay, 19% corn silage, 14% corn grain, and 30% concentrate mix on a DM basis, and it was fed ad libitum. Thirty primiparous and multiparous lactating Holstein cows (52 ± 23.0 DIM) were assigned to 1 of 3 dietary treatments with 10 cows in each treatment: control (TMR diet without ruminal buffer), TMR diet with 1.4% sodium bicarbonate (SBD), and TMR diet with 1.4% zeolite product (ZD). The experiment was a completely randomized design performed over 12 wk. Intake of DM was similar (26.5 kg/d) across treatments. Milk yield was similar among the 3 treatments (40.7 kg/d on average), and efficiency (4% FCM/DMI) was not affected by treatments. Milk fat concentration did not differ among treatments, whereas milk protein concentration tended to be higher for the ZD than for the control and the SBD (P = 0.15). Although feeding the ZD resulted in a tendency of increased milk protein concentration, feed nitrogen (N) efficiency for milk N did not differ among the 3 treatments. In addition, milk urea N concentration was not influenced by feeding the ZD. Ruminal pH tended to increase (P = 0.11) when feeding the SBD or the ZD compared with the control. Concentration of ammonia N did not differ among treatments. Feeding the ZD tended to decrease (P = 0.14) total VFA production compared with feeding the control and the SBD, whereas molar proportions of acetate and propionate were not affected by the treatments. The zeolite product used in this study would cost-effectively replace sodium bicarbonate as a ruminal buffer additive in a lactating dairy diet, but its efficacy needs to be further assessed when supplemented in a high-concentrate lactating dairy diet whereby animals may experience subacute ruminal acidosis.

Key words: lactating dairy cow, ruminal fermentation, sodium bicarbonate, zeolite

INTRODUCTION

Sizable inclusion of readily fermentable carbohydrate feedstuffs in dairy rations causes the appearance of digestive disorders such as subacute ruminal acidosis in dairy cattle if appropriate precautions are not taken. Strategic use of dietary ruminal buffers has been suggested as a sound approach to ameliorate the occurrence of ruminal acidosis, especially when lactating diets include large amounts of readily fermentable carbohydrate. Commonly used as an exogenous buffer, sodium bicarbonate ($NaHCO_3$) is involved in the stabilization of ruminal pH in cows that can potentially suffer from ruminal acidosis (Clark et al., 2009). This chemical feed additive is characterized by an acid dissociation constant (pKa = 6.25) that is close to the normal ruminal pH. Therefore, $NaHCO_3$ is generally recognized as an efficient buffer because of its high acid-consuming capacity in

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the rumen, and its mode of action is well documented (Erdman, 1988; Russell and Chow, 1993).

Any mineral additive to a diet is costly for the producer, and significant improvements in performance are not always achieved (Rogers et al., 1985; Harrison et al., 1986). Therefore, research is continuing to identify cheaper mineral buffers that exhibit the same mode of action as the established buffers. The natural zeolite clinoptilolite has a high attraction for water and a large number of cations, such as K^+, NH_4^+, Ca^{2+}, and Mg^{2+}, which can be reversibly bound or released, depending on the surrounding conditions (Mumpton, 1999). The high affinity of zeolites for water and osmotically active cations may facilitate ruminal fermentation, and osmotic activity may regulate pH in the rumen by buffering against hydrogen ions of organic acids. In addition, supplementing zeolite in dairy diets may improve nitrogen (N) utilization, because zeolite gradually releases excess ammonia (NH_3) in the rumen and allows rumen microorganisms to capture the NH_3 into microbial protein for assimilation into the animals' digestive systems (Mumpton, 1999).

Johnson et al. (1988) reported that ruminal pH increased when synthetic zeolite was added to the diet; however, the change in pH was only 0.2 units, and addition of the synthetic zeolite, with or without $NaHCO_3$, resulted in negative effects on feed intake, milk production, milk component yield, and nutrient digestibility in lactating Holstein cows. To our knowledge, there is a lack of experimental results regarding the effects of long-term feeding of lactating dairy cows with clinoptilolite, a natural zeolite, on its potential as a ruminal buffering agent.

The objectives of this study were 1) to investigate whether natural zeolite could replace $NaHCO_3$ as a buffer in the dairy cattle diet, and 2) to assess the effects of $NaHCO_3$ and natural zeolite additions on feed intake, milk production and composition, digestibility, and ruminal fermentation characteristics when added to a lactating dairy diet.

MATERIALS AND METHODS

Cows and Experimental Diets

The experiment was carried out using 30 Holstein cows consisting of 7 primiparous and 23 multiparous cows. At the start of the experiment, DIM averaged 52 ± 23.0. For 1 wk before feeding experimental diets, all cows were fed a diet without ruminal buffer. This 1-wk phase was used as the covariate period; thus milk yield and DMI were determined. At the end of the covariate period, 10 cows were assigned to 1 of 3 dietary treatments: control diet without ruminal buffer (**CD**), 1.4% sodium bicarbonate diet (**SBD**), and 1.4% clinoptilolite zeolite diet (**ZD**) on a DM basis. The cows were assigned to the dietary treatments based on previous milk yield, DIM, and parity. The experiment was conducted in a completely randomized design over 12 wk. Cows were weighed at approximately 0830 h at the beginning of the trial and end of wk 4, 8, and 12, and these weights were used to calculate the mean BW of cows for each month. Average BW was 676 ± 71.8 kg at the beginning of the experiment and 726 ± 70.2 kg at the end of the experiment. The dairy cows used in this study were cared for according to the Live Animal Use in Research Guidelines of Institutional Animal Care and Use Committee at Utah State University.

The diets contained 57% forage (67% alfalfa hay and 33% corn silage) and 43% concentrate mix on average (Table 1). The diets are typical for high-producing dairy cows in northern Utah, containing more alfalfa hay than corn silage, and baled alfalfa hay is commonly fed to provide 50 to 75% of the dietary forage, with total forage levels averaging 45 to 55% of the dietary DM. Diets were formulated based on NRC (2001) recommendations to provide sufficient NE_l and protein, vitamins, and minerals to produce 38 kg/d of milk with 3.5% fat and 3.0% true protein.

Table 1. Ingredient composition of the control diet

Ingredient	% DM
Alfalfa hay	37.9
Corn silage	19.3
Corn grain, steam flaked	13.7
Whole linted cottonseed	4.41
Cottonseed extender	2.82
Dried sugar beet pulp	5.69
Soybean meal, expeller	1.66
Canola meal	2.09
Molasses, sugar beet	1.20
Corn dried distillers grains with solubles	2.79
Corn hominy	5.47
Blood meal	1.10
Mineral and vitamin mix[1]	1.87

[1]Contained (per kg of DM) a minimum of 250,000 IU vitamin A, 65,000 IU vitamin D, 2,100 IU vitamin E, 400 mg Fe, 540 mg Cu, 2,100 mg Zn, 560 mg Mn, 15 mg Se, 35 mg I, 68 mg Co, and 19.6 g Rumensin (Elanco Animal Health, Greenfield, IN).

The clinoptilolite zeolite used in this study (RuMag™; ZeoTech Corporation, Fort Worth, TX) is a complex rumen buffer containing Mg- and Ca-exchanged zeolite and Mg and calcium hydroxide. The hydrothermal process used to chemically bond hydrate of Mg lime to high, cation-exchangeable and absorptive clinoptilolite zeolite results in a high-quality, prilled rumen buffer with bioavailable Mg and Ca conditioning properties of zeolite. The supplementation rate of clinoptilolite zeolite used in this study (1.4% DM) was based on the manufacturer's recommendation for an adult lactating dairy cow.

Cows were housed in individual tie stalls fitted with rubber mattresses, bedded with straw, and fed a TMR for ad libitum intake with at least 10% of daily feed refusal. All cows were individually fed twice daily at 0530 and 1630 h with approximately 60 and 40% of total daily feed allocation at each feeding, respectively. Feed offered and refused was recorded daily, and daily samples were collect-

ed to determine DMI. Cows had free access to water.

Cows were milked twice daily at 0500 and 1600 h. Milk production was recorded daily throughout the experiment. Cows were turned outside to a dry-lot for exercise for at least 1 h daily in the morning after being milked. Milk was sampled during the Wednesday p.m. and Thursday a.m. milkings of each week throughout the experiment. Milk samples were preserved with Broad Spectrum Microtabs II (D & F Control Systems Inc., San Ramon, CA) and stored at 4°C. Individual milk samples were analyzed for fat, true protein, lactose, and milk urea N by the Rocky Mountain DHIA Laboratory (Logan, UT) with mid-infrared wavebands (2 to 15 μm) procedures using an infrared instrument (Bentley 2000; Bentley Instruments, Chaska, MN) calibrated weekly using raw milk standards provided by Eastern Laboratory Services (Fairlawn, OH). An enzymatic procedure was used to determine milk urea N concentration using a Chemspec 150 instrument (Bentley Instruments). Milk composition was expressed on weighted milk yield of a.m. and p.m. samples. Milk fat and protein yields were calculated by multiplying milk yield from the respective day by fat and protein content of the milk of an individual cow.

Sample Collections, Calculations, and Chemical Analyses

Samples of the TMR fed and orts for individual cows were collected for 7 d at wk 4, 8, and 12, dried at 60°C for 48 h, ground to pass a 1-mm screen (standard model 4; Arthur H. Thomas Co., Philadelphia, PA), and stored for subsequent analyses. Analytical DM content of samples was determined by oven drying at 135°C for 3 h. Organic matter was calculated as the difference between DM and ash contents, with ash content determined by combustion at 550°C for 5 h. Measurement of CP (N × 6.25) was determined using an elemental analyzer (LECO TruSpec N, St. Joseph, MI) (AOAC, 2000; method 990.03). The NDF and ADF concentrations were sequentially determined using an ANKOM$^{200/220}$ Fiber Analyzer (ANKOM Technology, Macedon, NY) according to the methodology supplied by the company, which is based on the methods described by Van Soest et al. (1991). Sodium sulfite and heat-stable amylase (Type XI-A from *Bacillus subtilis*; Sigma-Aldrich Corporation, St. Louis, MO) were included in the analysis of NDF. Another set of dried, ground samples was sent to Cumberland Valley Analytical Service (Hagerstown, MD) to determine Ca, P, Mg, K, and Na (AOAC, 2000; method 985.01).

Digestibilities of feed DM and nutrients were measured at wk 4, 8, and 12 using AIA as an internal marker (Van Keulen and Young, 1977). Fecal samples (approximately 200 g wet weight) were collected for each cow from the rectum twice daily (a.m. and p.m.) every 12 h, moving ahead 2 h each day for the 6 d of fecal sampling. This schedule provided 12 representative samples of feces for each cow. Samples were immediately subsampled (about 50 g), composited across sampling times for each cow and each period, dried at 55°C for 72 h, ground to pass a 1-mm screen (standard model 4), and stored for chemical analysis. Apparent total-tract nutrient digestibilities were calculated from concentrations of AIA and nutrients in diets fed, orts, and feces using the following equation: apparent digestibility = $100 - [100 \times (AIA_d/AIA_f) \times (N_f/N_d)]$, where AIA_d = AIA concentration in the diet actually consumed, AIA_f = AIA concentration in the feces, N_f = concentration of the nutrient in the feces, and N_d = concentration of the nutrient in the diet actually consumed.

Ruminal fluid was taken using a Geishauser probe 4 h after the morning feeding on wk 4, 8, and 12. The fluid was collected with a solid, tube-like probe with rows of small holes on the end (Geishauser, 1993). Rumenocentesis is reported to be superior to the use of an oral stomach tube for determining ruminal pH because the latter technique is susceptible to saliva contamination (Nordlund and Garrett, 1994). However, rumenocentesis is a more invasive technique involving surgical preparation of the centesis site, as well as chemical and physical restraint, and it involves a risk of localized abscesses or peritonitis. An alternative technique developed by Geishauser (1993) uses a weighted oro-ruminal probe and suction pump, requires minimal time to perform, and is less invasive than rumenocentesis. The pH of the ruminal fluid was measured within 5 min of collecting the samples using a portable pH meter (Oakton pH 6; Oakton Instruments, Vernon Hills, IL). Five milliliters of the ruminal fluid was added to 1 mL of 25% meta-phosphoric acid, and the samples were retained for VFA determination. Another 5 mL of the ruminal fluid was mixed with 1 mL of 1% sulfuric acid for NH_3-N analysis. All samples were stored frozen (−40°C) until analysis.

Ruminal VFA were quantified using a GLC (model 6890 series II; Hewlett Packard Co., Avandale, PA) with a capillary column (30 m × 0.32 mm i.d., 1-μm phase thickness, Zebron ZB-FAAP; Phenomenex, Torrance, CA) and flame-ionization detection. The oven temperature was held at 170°C for 4 min, increased by 5°C/min to 185°C and then by 3°C/min to 220°C, and held at this temperature for 1 min. The injector temperature was 225°C, the detector temperature was 250°C, and the carrier gas was helium. Concentration of NH_3-N in the ruminal contents was determined as described by Rhine et al. (1998), using a plate reader (MRX^e; Dynex Technologies, Chantilly, VA).

Statistical Analyses

Daily intake and milk yield were reduced to weekly means before data analysis. Data for DMI, BW, and milk yield obtained during the covariate period were used as covariates for the corresponding measurements during the treatment period. An ANOVA was conducted using the MIXED procedure (Littell et al., 1998) of SAS

Table 2. Chemical composition of the treatment diets[1] on a DM basis

Item	CD	SBD	ZD
Ingredient (%)			
DM	64.5	64.4	63.9
CP	17.8	17.7	17.7
NDF	33.8	33.9	33.9
ADF	22.3	22.2	22.5
Ca	1.10	1.06	1.11
P	0.38	0.37	0.36
Mg	0.41	0.38	0.43
K	2.22	1.92	2.11
Na	0.233	0.395	0.255
NE_l[2] (Mcal/kg)	1.58	1.56	1.58

[1]CD = control diet without buffer; SBD = sodium bicarbonate diet composed of CD and sodium bicarbonate (1.4% DM); and ZD = zeolite diet composed of CD and clinoptilolite zeolite (1.4% DM).

[2]Based on tabular value (NRC, 2001).

(SAS Institute, 2001) for a completely randomized design with repeated measures for all the statistical analyses in this study. The model included the effects of treatment, week, and the interaction between treatment and week, with the random variable being the cow within treatment. Simple, autoregressive one, and compound symmetry covariance structures were used in the analysis depending on low values for the Akaike's information criteria and Schwartz's Bayesian criterion. For all models used, degrees of freedom were estimated with the Kenward-Roger specification in the models. Means were compared using a protected ($P < 0.05$) least significant difference test. Least squares means are reported throughout. Treatment effects were declared significant at $P < 0.05$, and differences were considered to indicate a trend toward significance at $0.05 < P < 0.15$.

RESULTS AND DISCUSSION

Chemical Composition of Diets

The CP, NDF, and ADF concentrations of alfalfa hay and corn silage were 18.6 ± 0.78 and 6.21 ± 0.401%, 40.0 ± 0.03 and 40.9 ± 0.28%, and 30.2 ± 0.28 and 22.8 ± 0.62%, respectively, indicating that the alfalfa hay was of good quality. Concentrations of CP, ADF, and NDF were similar among all dietary treatments (Table 2). Mineral concentrations did not differ across dietary treatments except that the SBD contained higher concentration of Na compared with the CD and ZD. All diets used in this study contained sufficient total NDF according to NRC (2001) recommendations. Generally, diets that are low in fiber are associated with ruminal acidosis, reduced rumination, saliva secretion, and fiber digestion (Yang and Beauchemin, 2006).

Table 3. Nutrient intake and total-tract digestibility of lactating dairy cows fed different ruminal buffer additives[1]

Item	CD	SBD	ZD	SEM	*P*-value
Intake (kg/d)					
DM	26.5	26.4	26.7	1.19	0.98
OM	23.7	23.8	23.9	1.07	0.99
CP	4.72	4.71	4.63	0.204	0.94
NDF	8.57	8.76	8.84	0.387	0.88
ADF	5.76	5.75	5.76	0.255	0.99
Digestibility (%)					
DM	72.9	72.5	73.0	0.47	0.72
OM	74.6	74.1	75.0	0.48	0.43
CP	77.2	76.8	76.9	0.46	0.79
NDF	47.9	48.0	48.7	1.03	0.83
ADF	45.9	44.7	44.0	1.20	0.57

[1]CD = control diet without buffer; SBD = sodium bicarbonate diet composed of CD and sodium bicarbonate (1.4% DM); and ZD = zeolite diet composed of CD and clinoptilolite zeolite (1.4% DM).

Intake, Digestibility, Milk Production and Composition, and Body Weight

Intake of DM averaged 26.5 kg/d across treatments and did not differ due to inclusion of sodium bicarbonate or zeolite (Table 3). This lack of effect across treatments on DMI was consistent throughout the experiment (Figure 1). Sherwood et al. (2006), using zeolite at 1.2% of DM, and Cole et al. (2007), using zeolite at 2.0% of DM, similarly reported no effect on DMI when supplementing zeolite to beef steer finishing diets. Previous work by Johnson et al. (1988) using lactating dairy cows showed a decrease in DMI when synthetic zeolite was added at 2.0% of dietary DM. Similar to our results, Johnson et al. (1988) found no effect on DMI with the addition of $NaHCO_3$ in dairy cow diets. Kennelly et al. (1999) reported that addition of $NaHCO_3$ did not affect intake of DM, CP, and NDF when cows were fed a high- or low-forage diet. Addition of either $NaHCO_3$ or zeolite in the diets assessed in this study did not influence intake of OM, CP, NDF, and ADF.

Digestibilities of DM and nutrients (OM, CP, NDF, and ADF) did not differ by the addition of $NaHCO_3$ or zeolite (Table 3). Supplementing finishing diets of beef steers with zeolite did not affect DM digestibility (Cole et al., 2007). Johnson et al. (1988) reported lower digestibilities of DM and OM with added synthetic zeolite but suggested that part of this reduction could be attributed to consumption of the indigestible synthetic zeolite. In addition, the authors observed that CP digestibility decreased but ADF digestibility did not differ with added synthetic zeolite (Johnson et al., 1988). However, Cole et al. (2007) reported that digestibility of CP was not affected by addition of 1.0 or

2.0% zeolite to the diets of finishing steers. Similar to our result, Johnson et al. (1988) showed that addition of sodium bicarbonate did not affect apparent digestibilities of DM and OM.

Yield of milk and 4% FCM averaged 40.7 and 40.0 kg/d, respectively (Table 4), and were similar in response to the addition of $NaHCO_3$ or zeolite. Lack of effect of supplementing the ruminal buffers on milk yield was consistent throughout the experiment (Figure 1). It seems that the zeolite at 1.4% DM used in this study was too low to affect milk yield. Similar to our result, Katsoulos et al. (2006) and Bosi et al. (2002) observed no difference in milk yield of dairy cows supplemented with zeolite at 1.25 and 1.0% on a DM basis, respectively. However, dairy cows fed 2.5% (Katsoulos et al., 2006) and 2.0% DM zeolite (Garcia Lopez et al., 1992) increased milk yield. Katsoulos et al. (2006) speculated that the higher milk production by cows fed 2.5% zeolite could be due to increased production of propionate in the rumen or increased postruminal digestion of starch. On the other hand, Johnson et al. (1988) reported that supplementing synthetic zeolite at 2.0% decreased milk yield as well as 4% FCM yield, and the reduction in milk yield was likely associated with decreased DMI and digestibility.

Milk composition and yield were not influenced by supplementing ruminal buffers except that feeding the ZD tended to increase milk true protein concentration ($P = 0.15$; Table 4). In general, it has been accepted that dietary buffers do not consistently alter protein percentage of milk (Cassida et al., 1988; Harrison et al., 1989; Xu et al., 1994). Despite the tendency of zeolite supplementation to increase milk protein concentration, milk urea N and efficiency of N use for milk N were not affected by dietary treatments. Dairy efficiency, calculated as 4% FCM divided by DMI, was not influenced by dietary treatments. In addition, mean BW and BW change were similar among dietary treatments.

Ruminal Fermentation Characteristics

Ruminal pH tended to increase ($P = 0.11$) when supplementing $NaHCO_3$ or zeolite (Table 5). Johnson et al. (1988) reported an increase in ruminal pH when synthetic zeolite was added to the diet; however, like in our case, the change was only 0.2 units. Bosi et al. (2002) reported no effect of supplementing zeolite at 1.0% DM on ruminal pH when dairy cows were fed a typical lactation diet with a forage-to-concentrate ratio of 45:55. In beef finishing feedlot diets, the addition of zeolite at 1.2% DM increased ruminal pH (Eng et al., 2006). Survival rates of cellulolytic bacteria decrease when pH drops to less than 6.2 (Calsamiglia et al., 1999), thus reducing fiber digestion and causing various negative effects on ruminal fermentation. Because the ruminal pH in the CD was 6.42, which is over 6.2, the increase in ruminal pH of 0.12 units and 0.19 units by the SBD and the ZD, respectively, would have no physiological significance and would not affect overall ruminal fermentation.

High-concentrate diets are often associated with lower ruminal pH and decreased fiber digestibility (Yang et al., 2002; Eun and Beauchemin, 2005). Ruminal buffers have been shown to prevent milk fat depression associated with feeding corn silage or low-fiber diets (Harrison et al., 1989; Xu et al., 1994; Kennelly et al., 1999) by helping to stabilize rumen pH and thus providing a more favorable environment for microbial growth. Marden et al. (2008) reported that stabilization of ruminal pH with $NaHCO_3$ was not associated with a lower lactate concentration and consequently suggested that $NaHCO_3$ may have stabilized the pH through its strong capacity to neutralize protons (Le Ruyet and Tucker, 1992). Erdman et al. (1982) reported an increase in rumen pH, from 6.13 to 6.43, in early lactating dairy cows receiving 1.0% $NaHCO_3$. Therefore, to offset the potential negative effect of high-concentrate diets on the rumen environment, supplementing a buffer in lactating diets is recommended. However, such benefits have not been observed from the addition of buffer to diets that contained alfalfa as the primary forage (Bath et al., 1985). The experimental diets assessed in this study contained 38% alfalfa hay

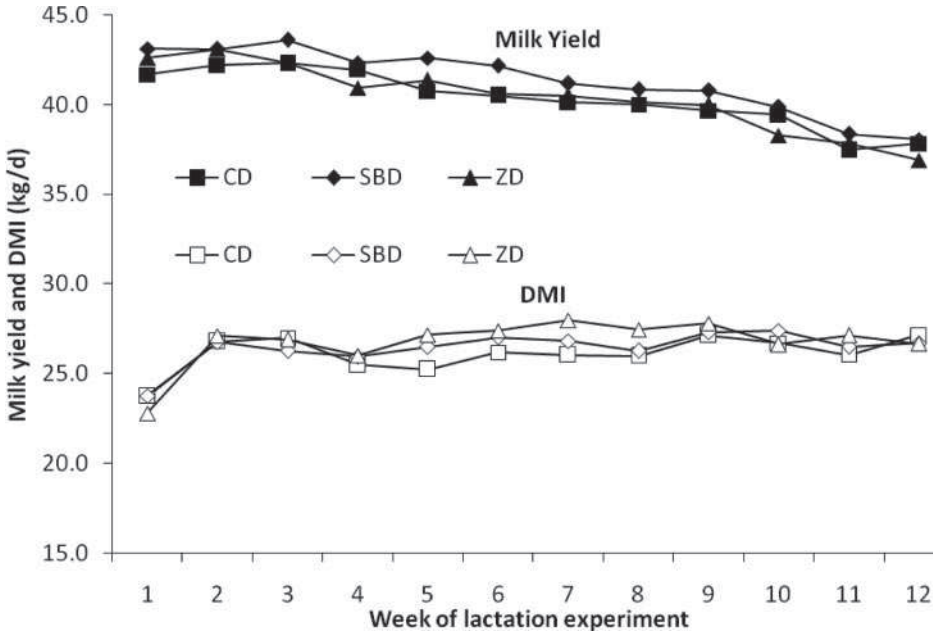

Figure 1. Dry matter intake and milk yield of lactating dairy cows fed different ruminal buffer additives. Treatments were TMR without buffer (CD), CD and sodium bicarbonate TMR (SBD), and CD and zeolite TMR (ZD). Each point represents the mean of 10 observations (SEM = 1.19 and 1.46 for DMI and milk yield, respectively).

Table 4. Milk production and composition, efficiencies of DM and N use, and BW of lactating dairy cows fed different ruminal buffer additives[1]

Item	CD	SBD	ZD	SEM	*P*-value
Milk production (kg/d)					
Actual	41.5	41.0	39.6	1.46	0.62
4% FCM	40.1	40.2	39.5	1.54	0.94
Milk composition (%)					
Fat	3.77	3.94	3.84	0.100	0.48
True protein	2.94	2.93	3.09	0.063	0.15
Milk urea nitrogen (mg/dL)	14.7	14.2	13.4	0.48	0.18
Milk component yield (kg/d)					
Fat	1.57	1.62	1.52	0.079	0.70
True protein	1.21	1.20	1.22	0.056	0.98
Efficiency					
4% FCM/DMI	1.54	1.56	1.43	0.077	0.49
Milk N/N intake[2]	0.27	0.26	0.27	0.008	0.56
BW (kg)	709	704	707	5.2	0.74
Change in BW (kg/d)	0.34	0.30	0.32	0.049	0.82

[1]CD = control diet without buffer; SBD = sodium bicarbonate diet composed of CD and sodium bicarbonate (1.4% DM); and ZD = zeolite diet composed of CD and clinoptilolite zeolite (1.4% DM).

[2]Efficiency of use of feed nitrogen to milk nitrogen = (total milk protein, kg/d ÷ 6.38) ÷ nitrogen intake, kg/d.

of high quality, being clean, bright green, and fine stemmed. Feeding a high-forage diet would have reduced the rate of fermentation acid production in the rumen, because less starch is fermented in the rumen compared with when feeding a high-concentrate diet (Yang and Beauchemin, 2006). Therefore, it is likely that a high-forage NDF concentration with high-quality alfalfa hay provided a normal, fermentative environment, eliminating potentially positive effects of supplementing $NaHCO_3$ or zeolite. Further research is needed to determine if supplementing zeolite in a high-concentrate, lactating diet would prove effective by increasing ruminal pH, because feeding the high-concentrate diet will lower ruminal pH with more fermentable carbohydrate in the diet.

Total VFA concentration tended to decrease ($P = 0.14$) when cows were fed the ZD (Table 5), whereas molar proportions of major VFA (acetate, propionate, and butyrate) and acetate-to-propionate and acetate+butyrate-to-propionate ratios were not affected by dietary treatment. Decreased total VFA concentration by the ZD would not have resulted in a lower fiber digestion, because digestibilities of NDF and ADF were not influenced by supplementing buffers. Bosi et al. (2002) observed that the inclusion of zeolite in the diet of lactating dairy cows had no effect on concentration and molar proportion of VFA. Johnson et al. (1988) reported no effect on ruminal VFA concentration with inclusion of $NaHCO_3$; however, the authors reported that propionate decreased with added synthetic zeolite, whereas other VFA were unaffected (Johnson et al., 1988). The effects of supplementing zeolite on ruminal VFA composition have been variable among studies. For instance, McCollum and Galyean (1983) observed that when steers were fed high-concentrate diets, molar proportion of propionate increased with the addition of 2.5% DM zeolite in their ration but not when 1.5% DM was added. Katsoulos et al. (2006) reported that supplementation of a concentrate diet for dairy cows with 2.5% DM of zeolite reduced the incidence of clinical ketosis and increased milk yield. The authors suggested that the positive effects could have resulted from possible enhancement of propionate production in the rumen (Katsoulos et al., 2006). In contrast, Sweeney et al. (1984) observed a decrease in propionate and an increase in acetate, resulting in increased acetate-to-propionate ratio when Holstein steers and heifers were fed 5% clinoptilolite zeolite. Similarly, Johnson et al. (1988) reported an

Table 5. Ruminal fermentation characteristics of lactating dairy cows fed different ruminal buffer additives[1]

Item	CD	SBD	ZD	SEM	*P*-value
Ruminal pH	6.42	6.54	6.61	0.061	0.11
Total VFA (m*M*)	114.4	113.8	103.8	4.44	0.14
Individual VFA (mol/100 mol)					
Acetate (A)	62.8	62.5	63.9	0.74	0.37
Propionate (P)	22.4	22.0	21.6	0.70	0.74
Butyrate (B)	10.8	11.0	10.5	0.21	0.17
Valerate	1.68	1.81	1.69	0.633	0.28
Isobutyrate	0.82[b]	0.97[a]	0.81[b]	0.027	<0.01
Isovalerate	1.17[b]	1.39[a]	1.18[b]	0.058	0.02
A:P	2.85	2.90	3.01	0.124	0.65
(A + B):P	3.33	3.41	3.50	0.140	0.70
NH_3-N (mg/dL)	10.7	11.6	11.7	0.68	0.58

[a,b]Means within a row that do not have a common superscript differ at $P < 0.05$.

[1]CD = control diet without buffer; SBD = sodium bicarbonate diet composed of CD and sodium bicarbonate (1.4% DM); and ZD = zeolite diet composed of CD and clinoptilolite zeolite (1.4% DM).

increase in the acetate-to-propionate ratio with synthetic zeolite, but because acetate concentration was unchanged, the higher ratio was the result of decreased propionate.

Concentration of ruminal NH_3-N was not affected by dietary treatment. Similar to our result, Bosi et al. (2002) reported ammonia level in ruminal fluid was not affected by feeding zeolite to lactating dairy cows at 1.0% of dietary DM. Johnson et al. (1988) reported ruminal NH_3-N was not affected by addition of synthetic zeolite or $NaHCO_3$ in dairy cattle diets. In contrast, Hemken et al. (1984) reported a decrease in the concentration of NH_3-N when feeding natural zeolite to dairy cows, but the positive effect of supplementing zeolite was obtained when cows were fed a diet containing urea as a source of protein. Mumpton and Fishman (1977) reported that the zeolite's ability to act as a reservoir can result in protection of the animal against ammonia overload in the rumen. It is possible that, after the release of ammonia consequent to each meal, zeolite absorbs high levels of NH_3 concentration in the rumen and then releases NH_3 when its concentration is reduced (Bosi et al., 2002), which may explain the lack of effects of supplementing NH_3-N concentration in this study. Although adsorption sites on zeolite may be tied up by ammonia in the rumen and thus limit the capacity of excreted zeolite to bind ammonia on the pen surface, some studies suggest that the feeding of zeolite may reduce N losses from manure (Eng et al., 2003; Cole et al., 2007). Cole et al. (2007) reported that zeolite addition to the feedlot pen surface using an in vitro ammonia emission system (Cole et al., 2005) decreased ammonia losses by 51 to 86%; however, apparent CP digestibility and N retention and excretion were not affected by addition of zeolite in beef finishing diet. The slow rate of NH_3 emission could render zeolite more effective at adsorbing ammonium because of the longer time for contact between the ammonium and zeolite in the manure.

The most significant findings in this study were that supplementing natural zeolite in lactation dairy diet had minor effects on ruminal fermentation and lactational performance of dairy cows. The lack of effects of supplementing the ruminal buffer was consistent throughout the long-term feeding experiment during early to midlactation. High NDF concentration together with high dietary proportion of high-quality alfalfa hay may dilute potential effects of supplementing natural zeolite in the experimental diet assessed in this study. Further research is needed on the zeolite used in this study to determine if the product influences ruminal fermentation characteristics when added to high-concentrate, lactation dairy diets, with focus on its potential to reduce subacute ruminal acidosis.

IMPLICATIONS

Supplementing zeolite had no negative effects on productive performance and ruminal fermentation except for a tendency to reduce VFA production, which indicates that the zeolite product used in this study would replace $NaHCO_3$ as a ruminal buffer additive cost effectively in lactation dairy diets. In addition to zeolite maintaining the rumen environment similarly to $NaHCO_3$, an additional finding of a trend toward increased milk protein and the estimated cost of zeolite projected to be lower than $NaHCO_3$ suggest that the net income of the farmer will increase when using this product. The real test will be when this product is used in a low ruminal pH fermentative environment. With its increased exchange rate for ions, the difference may be greater than in the current study.

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