Impact of Feeding a Raw Soybean Hull-Condensed Corn Steep Liquor Pellet on Induced Subacute Ruminal Acidosis in Lactating Cows¹

J. M. DeFraín,^{*,2} J. E. Shirley,^{*} E. C. Titgemeyer,^{*}
A. F. Park,^{*} and R. T. Ethington[†]

^{*}Department of Animal Sciences and Industry

Kansas State University, Manhattan 66506

[†]Minnesota Corn Processors, LLC, Marshall, MN 56258

ABSTRACT

We used four ruminally cannulated, multiparous Holstein cows (690 kg; 21 kg/d milk) in a 2-period crossover design to determine the impact of feeding a raw soybean hull-corn steep liquor pellet (SHSL) on induced subacute ruminal acidosis (SARA) in lactating cows. Cows were fed control [30% alfalfa hay, 15% corn silage, 34% corn, 9% whole cottonseed, 5% soybean meal (SBM)] or SHSL (20% of diet DM) diets as TMR. SHSL replaced 6.2% alfalfa hay, 3.7% corn silage, 6.6% corn, and 3.3% SBM. Periods were 15 d (10 d adaptation, 2 d for prechallenge measures, and 3 d of SARA challenge). Cows were fed once daily at a common DMI dictated by the cow consuming the least. Cows were fasted 12 h before the first SARA challenge. For each of the three SARA challenges, cows were offered 75% of their daily diet at 0600 h. The remaining 25% of diet DM was replaced by ground corn, which was mixed with theorts that remained 2 h after feeding and placed into the rumen. Ruminal pH declined linearly with time after feeding, and this decrease was greater during the SARA challenges. Ruminal lactate increased linearly with repeated SARA challenges. Concentrations of total ruminal VFA increased linearly after feeding, and increases were greater when cows were challenged. No differences were observed due to SHSL inclusion. The model induced SARA, but partial replacement of alfalfa, corn silage, corn, and SBM by SHSL did not influence responses to SARA challenges.

(Key Words: acidosis, soyhull, corn steep liquor)

Abbreviation key: CSL = condensed corn steep liquor, NFC = nonfiber carbohydrate using $100 - (\% \text{ CP}$

+ % NDF + % ether extract + % ash), **SARA** = subacute ruminal acidosis, **SBM** = soybean meal, **SHSL** = raw soybean hull-condensed corn steep liquor pellet.

INTRODUCTION

Formulating energy-dense diets to meet the nutritional requirements of high producing dairy cows can promote subacute ruminal acidosis (**SARA**). Furthermore, the use of rapidly fermentable carbohydrates to meet energy demands often results in a decrease in milk fat (Sutton, 1989), which has been associated with suboptimal ruminal pH and acetate:propionate ratio (Sarwar et al., 1992). Conversely, high fill diets, which are formulated to provide adequate physically effective fiber to maximize buffering activity by stimulating rumination and salivation, often limit the animal's nutrient intake capabilities and result in decreased milk production (Varga et al., 1984). Diets high in NDF can be formulated using nonforage fiber sources such that starch content is lower than in diets containing primarily forage NDF. Potentially, this could alleviate the negative effects of starch on fiber digestion (Mertens and Lofton, 1980). Yet, most nonforage fiber sources do not stimulate chewing activity (Clark and Armentano, 1997), potentially subjecting cows to SARA.

Raw soybean hulls are a nonforage fiber source readily available in the Midwest United States. They provide a highly digestible source of structural fiber with minimal lignin content (Garleb et al., 1988). However, compared with forages, soyhulls do not stimulate rumination and can lead to reduced ruminal pH (Weidner and Grant, 1994a). Dietary ingredients replaced by soyhulls largely influence the observed effects on ruminal acidity. When substituting soyhulls for mostly forage, reduced ruminal pH was reported (Sarwar et al., 1991; Cunningham et al., 1993), but when soyhulls replace a portion of the concentrate, only insignificant changes in ruminal pH occur (Sarwar et al., 1992; Cunningham et al., 1993).

Received December 11, 2001.

Accepted February 4, 2002.

Corresponding author: J. E. Shirley; e-mail: jshirley@oznet.ksu.edu.

¹Contribution Number 02-199-J Kansas Agricultural Experiment Station, Manhattan.

²Present address: Dairy Science Department, South Dakota State University, Brookings, SD 57007-0647.

Condensed corn steep liquor (**CSL**), a byproduct of the wet corn milling industry, contains a mixture of carbohydrates, amino acids, peptides, organic compounds, heavy metals, inorganic ions, and *myo*-inositol phosphates (Hull et al., 1996). Johnson et al. (1962) reported significantly higher crude fiber, cellulose, and DM digestibilities when lambs fed a 50% roughage diet were supplemented with CSL. Corn steep liquor also has been used successfully as a protein supplement for beef cattle grazing dormant winter range (Wagner et al., 1983). Paradoxically, in vitro ruminal fermentation evaluations indicated CSL had a positive effect on starch digestion but a negative effect on cellulose digestion when compared to soybean meal (**SBM**; Filho, 1999).

Our laboratory has developed a pelleted feedstuff (**SHSL**) containing 75% raw soybean hulls and 25% CSL (DM basis). Previous research indicated SHSL is a palatable product that is high in fiber and protein and suitable for lactating dairy cattle diets (DeFrain et al., 2001). Substituting SHSL for a portion of forage and grain, the fiber (29% ADF, 37% NDF) of raw soybean hulls and CP of CSL (44.2%) may enhance nutrient delivery to the dairy cow without causing SARA.

Our experiments were designed to determine the ruminal fermentation pattern of cows fed SHSL and to evaluate the effect of SHSL when consumed by cows experimentally challenged with SARA.

MATERIALS AND METHODS

In Vitro Acid Buffering Capacity

The acid buffering capacity of alfalfa hay, corn grain, raw soybean hulls, and SHSL were evaluated in vitro. Acid buffering capacity was measured in triplicate using procedures from Jasaitis et al. (1987). Samples were ground using a Wiley mill (1-mm screen), dried for 24 h at 105°C; DM was assumed to be 100%. After air-equilibrating, 0.5 g was suspended in 50 ml of deionized water. Using a pH meter equipped with a combination electrode (Orion, Boston, MA), initial pH and further measurements were recorded after 3 min of equilibration, during which time contents were continuously stirred using a magnetic stir bar. Acid titrations were performed by adding 0.1 N HCl in variable increments (depending upon stage of titration) until sample pH was decreased to 4, at which time total volume of acid added was recorded. Acid buffering capacity was calculated as [(total volume of acid required $\times$ 0.1 N HCl)/(initial pH - 4)].

SARA Challenge

Four ruminally cannulated (10-cm i.d., Bar Diamond, Inc., Parma, ID), multiparous Holstein cows

Figure 1. Feeding and sampling protocol used to induce subacute ruminal acidosis (SARA).

(690 kg; 21 kg of milk/d) were used to investigate the effect of SHSL on rumen fermentation and SARA during an experimental challenge. Cows were housed in tie-stall facilities at the Kansas State University Dairy Teaching and Research Center (Manhattan, KS). All cows were administered recombinant bovine somatotropin (Posilac, Monsanto, St. Louis, MO) at 14-d intervals throughout the trial. Periods were 15 d (10-d adaptation, 2 d for prechallenge measures, and 3 d of subacute ruminal acidosis challenge) and separated by 10 d to eliminate carryover effects. A graphic representation of the experimental protocol is illustrated in Figure 1.

Dietary treatments (Table 1) were control and SHSL fed at 20% of diet DM. This level of SHSL inclusion was based on data from an acceptability trial using lactating dairy cows (DeFrain et al., 2001). Concentrations of NEL, crude protein, ADF, and NDF were formulated to be similar between diets by replacing portions of alfalfa hay, corn silage, ground corn, and solvent soybean meal with SHSL. Expeller soybean meal replaced solvent soybean meal in the SHSL diet to equalize diet RUP. Concentrations of menhaden fish meal and blood meal were similar between treatments.

A Data Ranger feed cart (American Calan, Northwood, NH) was used to mix diets daily at 0530 (all phases) and 1630 h (d 1 through 6). During the first 6 d of the 10-d adaptation phase, TMR and ort samples were collected daily and dried at 105°C to determine daily intake. During d 7 to 12, cows were fed once daily at a common DMI as a percent of BW dictated by the cow consuming the least during the first 6 d of adaptation. Cows were fasted 12 h before the first SARA challenge. For each SARA challenge (d 13, 14, and 15), cows were offered 75% of their daily diet at 0600 h. The remaining 25% of diet DM was replaced by ground corn (average particle size of 2500 μ) that was mixed with Orts remaining 2 h after feeding (see Table 3 below) and placed into the rumen at that time.

Table 1. Ingredient and nutrient composition of diets.

Item	Control		SHSL ¹	
	Prechallenge	Challenge	Prechallenge	Challenge
	(% of DM)			
Ingredient				
Alfalfa hay	30.0	22.5	23.7	17.7
Corn silage	15.0	11.2	11.2	8.4
Whole cottonseed	9.3	6.9	9.3	6.9
Corn grain, ground	34.0	50.5	27.5	45.5
Soybean meal, 48% CP	5.0	3.7	...	...
Expeller soybean meal	...	...	1.7	1.2
SHSL pellet ¹	...	...	20.0	15.0
Wet molasses	1.00	0.75	1.00	0.75
Fish meal	2.00	1.50	2.00	1.50
Blood meal	0.50	0.38	0.50	0.38
Dicalcium phosphate	0.43	0.32	0.15	0.11
Limestone	1.40	1.05	1.61	1.21
Sodium bicarbonate	0.67	0.50	0.67	0.50
Magnesium oxide	0.210	0.158	0.210	0.158
Trace mineralized salt ²	0.320	0.240	0.320	0.240
Vitamin ADE premix ³	0.128	0.097	0.128	0.097
Sodium selenite premix ⁴	0.014	0.011	0.014	0.011
Nutrient				
CP, %	16.6	15.0	16.2	14.1
RUP, % of CP	44.2	47.5	50.6	53.6
NE _L , Mcal/kg	1.78	1.84	1.72	1.80
Ether extract, %	5.95	5.17	5.13	4.38
NDF, %	26.8	22.0	27.4	22.1
ADF, %	19.1	15.0	20.5	16.0
NFC, % ⁵	44.0	52.1	44.5	53.7
Ash, %	6.62	5.72	6.73	5.74
Ca, %	1.10	0.91	0.68	0.58
P, %	0.48	0.44	0.45	0.39
S, %	0.18	0.16	0.23	0.19

¹Pellet containing 75% raw soybean hulls, 25% corn steep liquor (DM basis); Composition (DM basis): 85.7% DM, 25.6% CP, 39.3% RUP (% of CP), 3.4% Ether extract, 34.6% NDF, 27% ADF, 28.8% NFC, 7.6% ash, 0.40% Ca, and 0.78% P.

²Composition: not less than 95.5% NaCl, 0.24% Mn, 0.24% Fe, 0.05% Mg, 0.032% Cu, 0.032% Zn, 0.007% I, 0.004% Co.

³Contributed 5,733 IU vitamin A, 2,866 IU vitamin D, and 17 IU vitamin E per kg diet DM.

⁴Contained 600 mg of Se per kg of premix.

⁵NFC = 100 - (% NDF + % CP + % ether extract + % ash).

Sampling and laboratory analysis. Samples of dietary components (alfalfa hay, corn silage, whole cottonseed, concentrate, and SHSL) were collected on d 10 of each period, frozen (−20°C), composited across period at the end of the trial, and analyzed by Northeast DHI Forage Testing Laboratory (Ithaca, NY). Crude protein was measured as Kjeldahl N × 6.25. *Streptomyces griseus* enzymatic technique was used to measure protein degradability using the method of Roe and Sniffen (1990) for concentrates and the method of Coblenz et al. (1999) for forages. In addition, NDF, ADF, and lignin were measured using the ANKOM A200 (ANKOM Technology Corp., Fairport, NY) filter bag technique. Ether extract was measured using the automated Tecator Soxtec System HT6 (FOSS North America, Eden Prairie, MN). Nonfiber carbohydrate (NFC) was calculated by difference us-

ing the equation: % NFC = 100 - (% CP + % NDF + % ether extract + % ash). Ingredient TDN was calculated using the equations of Weiss et al. (1992). The NE_L of concentrates was calculated according to NRC (1988), whereas forage NEL values were according to Van Soest and Fox (1992).

Approximately 500 ml of rumen fluid was collected from below the ruminal mat before feeding and 3, 6, 9, and 12 h after feeding during d 11 to 15. Collected fluid was strained through four layers of cheesecloth, and pH was measured immediately using a portable pH meter equipped with a combination electrode. Following pH determination, an 8-ml sample of filtered fluid was mixed with 2 ml of 25% (wt/vol) metaphosphoric acid and frozen at −20°C until analyzed for concentrations of VFA, NH₃, and lactic acid. Samples for analysis of free amino acids and peptides were handled

and measured as described by Wessels et al. (1996), except a Technicon AutoAnalyzer III (Technicon Industrial Systems, Tarrytown, NY) was used.

Samples collected for NH_3 , lactate, and VFA were thawed and centrifuged at $30,000 \times g$ for 20 min at 4°C . Ammonia concentrations were measured using a Technicon AutoAnalyzer III (Technicon industrial method no. 337-74T) following the general protocol of Broderick and Kang (1980). Concentrations of lactic acid were measured using the procedure of Barker and Summerson (1941). Concentrations of VFA were measured by gas chromatography (model 5890, Hewlett-Packard, Avondale, PA) using N_2 as a carrier gas (80 ml/min) and a flame-ionization detector. Column ($1.9 \text{ m} \times 6.35 \text{ mm i.d.}$, Supelco packing # 1-1965; GP 10%; SP-1200/1%, H_3PO_4) and detector temperature were maintained at 130 and 225°C , respectively.

Statistical analysis. Analysis of variance was conducted using SAS (1990). Data were analyzed as a split-split-plot design using the MIXED procedure (Littell et al., 1996) with the main plot as replicated 2×2 Latin squares, day of each period as the split-plot, and hour within collection day as the split-split plot. Data collected during both days of the 2-d pre-challenge period were considered equivalent, whereas each of the three challenge days were considered as separate sampling days. The model included period, diet, d, diet $\times$ d, h, diet $\times$ h, d $\times$ h, and diet $\times$ d $\times$ h. Cow, cow $\times$ period $\times$ diet, and cow $\times$ period $\times$ diet $\times$ d were included as random variables with the latter two terms serving as the main plot error term and the subplot error term, respectively. Effects of day were separated using contrasts for 1) pre- versus postchallenge, 2) linear effect of day within the challenge days, and 3) quadratic effect of d within the challenge days. Effects of hour were separated using contrasts for linear, quadratic, cubic, and quartic responses. Interactions were separated into single degree of freedom contrasts using the interactions of the previously listed contrasts.

RESULTS AND DISCUSSION

In Vitro Acid Buffering Capacity

In vitro acid buffering capacity data are presented in Table 2. Acid buffering capacity expresses the amount of acid required to produce a one-unit change in pH. Acid buffering capacity for alfalfa hay and raw soybean hulls were 0.15 and 0.07, respectively. These were similar to those reported by Jasaitis et al. (1987), and the acid buffering capacity of SHSL (0.19) was similar to alfalfa hay. Jasaitis et al. (1987) reported that the buffering capacity of high protein feedstuffs ($>35\%$ CP) is greater than feeds containing 15 to 35%

Table 2. In vitro acid buffering capacity of alfalfa hay, corn, raw soybean hulls, and a pellet containing 75% raw soybean hulls, 25% corn steep liquor (DM basis; SHSL).

Ingredient	n	Initial pH	0.1 N HCl, ml ¹	Acid buffering capacity ²
Alfalfa hay	3	5.79	2.73	0.15
Corn	3	6.10	0.60	0.03
Raw soybean hulls	3	6.16	1.60	0.07
SHSL	3	4.62	1.20	0.19
SEM		0.19	0.24	0.019

¹ml 0.1 N HCl required to lower 0.5 g sample in 50 ml water to pH 4.

²Millimoles acid per unit change in pH, calculated as (ml HCl $\times$ 0.1 N HCl)/(initial pH - 4).

CP or feeds classified as energy sources. The crude protein content of the alfalfa hay and SHSL were 20.9 and 25.6%, respectively. Wohlt et al. (1987) noted that protein content influences buffering capacity and also concluded that the numerical buffering capacity values of feedstuffs are not useful because the slope of the titration curves differed among different types of feeds. Therefore, the experimentally induced SARA study was conducted to verify the in vitro results.

SARA Challenge

High producing dairy cows require effective fiber to maintain normal rumen function, but too much fiber can reduce DMI and milk production (Varga et al., 1984). Highfill et al. (1987) demonstrated that soyhulls can increase energy content without decreasing fiber digestion. In the present study, substituting SHSL for 10% of the forage DM did not affect diet NDF levels but reduced the forage-to-concentrate ratio from 45:55 for the control diet to 35:65 for the SHSL diet. Reducing the forage-to-concentrate ratio by feeding SHSL at the expense of forage fiber may subject cows to a greater risk for developing SARA. Therefore, a

Table 3. Effect of induced subacute ruminal acidosis (SARA) challenge on DMI of cows fed a pellet containing 75% raw soybean hulls, 25% corn steep liquor (SHSL, DM basis) or control.

Day within period	Control	SHSL	SEM
	kg/d		
1 to 6	23.2	22.5	1.0
7 to 12	18.5	20.3	0.8
2 h post feeding			
13	10.0	10.2	1.3
14	7.7	7.7	1.0
15	7.8	7.2	1.1
Amount placed in rumen			
13	9.9	9.7	1.0
14	12.1	12.7	1.2
15	12.8	13.5	1.4

Figure 2. Effect of induced subacute ruminal acidosis (SARA) challenge on daily milk yields (SEM = 0.43) of cows fed a pellet containing 75% raw soybean hulls, 25% corn steep liquor (SHSL, DM basis, ○) or control (△).

SARA challenge model was developed to evaluate diets that are similar in diet NDF but differ in forage NDF content.

General observations. Ingredient and nutrient composition of experimental diets are shown in Table 1. Replacing 25% of diet DM with ground corn during the SARA challenges resulted in an energy-dense, highly fermentable diet that promoted accumulation of ruminal VFA. During SARA challenges, diet NFC increased by 7.7 and 9.1%, and diet NDF from forage decreased by 5.8 and 3.7% for cows fed control and SHSL, respectively. Effect of dietary treatment and induced SARA on DMI is shown in Table 3. During the adaptation phase, lowest and average DMI were 2.9 and 3.3% of BW, respectively. Amount of TMR consumed 2 h after feeding during SARA challenges was similar for cows fed control and SHSL. Challenging cows with SARA reduced voluntary DMI 2 h after feeding. Independent of dietary treatment, milk yields decreased similarly during the induced SARA challenges (Figure 2). Because the cow with the lowest DMI determined the amount of feed offered, the observed decrease in milk production was likely a result of the restriction of feed intake.

Ruminal parameters. Effects of diet and SARA challenges on ruminal pH are shown in Figure 3. As expected, ruminal pH declined linearly with time after feeding, and these decreases were greater during the SARA challenges ($P < 0.01$). During the prechallenge days, ruminal pH was numerically lower for cows fed SHSL. These results are in agreement with Weidner and Grant (1994a), who reported lower ruminal pH values when soyhulls replaced a portion of the forage

Figure 3. Effect of induced subacute ruminal acidosis (SARA) challenge on ruminal pH, total VFA, and lactate concentrations of cows fed a pellet containing 75% raw soybean hulls, 25% corn steep liquor (SHSL, DM basis, ○) or control (△).

fiber. Corn steep liquor has increased starch digestion *in vitro* (Filho, 1999), which could have contributed to the lower ruminal pH observed for cows fed SHSL. Effects of diet on the severity of ruminal pH depression were similar during the SARA challenges, indicating that feeding SHSL did not exacerbate the risk for cows to develop SARA under these feeding conditions.

These results are attributed to substituting SHSL for portions of both forage and concentrates, which allowed diet NFC and NDF to be similar to the control diet. Nagaraja et al. (1998) indicated that SARA is present when ruminal pH values are between 5.0 and 5.5. Considering that ruminal pH values were within this range during the second and third challenges of the present study, the model used to induce SARA was effective.

Concentrations of total ruminal VFA increased linearly ($P < 0.01$) after feeding, and increases were, on average, 30% greater on challenge days relative to prechallenge days (Figure 3). During the SARA challenges, linear and quadratic responses ($P < 0.05$) were observed for ruminal acetate and butyrate concentrations (Figure 4). Prior to SARA challenges, concentrations of ruminal propionate (Figure 4) were higher for cows fed SHSL than for those fed control. Weidner and Grant (1994b) observed a 22% increase in propionate when soyhulls were substituted for 42% of an alfalfa:corn silage mix in diets fed to early-lactation cows. Similar to the *in vitro* work of Erfle et al. (1982), decreases in ruminal pH after feeding were associated with linear increases in propionate during SARA challenges, resulting in a linear decrease in the acetate:propionate ratios (Figure 5). These results are also similar to those of Goad et al. (1998), who induced SARA in steers that were first adapted to an 80% grain-based diet. Nagaraja et al. (1998) indicated increases in total VFA concentrations are often observed in animals experiencing SARA. Although no significant differences were observed between diets, branched-chain VFA concentrations were reduced ($P < 0.01$) with SARA challenges and declined at a faster rate after feeding on challenge days (Figure 4). Branched-chain VFA are primarily derived from degraded feed protein or endogenous branched-chain amino acids (Allison and Bryant, 1963). Others (Erfle et al., 1982) reported decreases in branched-chain fatty acid concentrations when pH was lowered (from 6.5 to 5.5) in a continuous culture system. These authors (Erfle et al., 1982) attributed the observed changes to shifts in microbial populations, which likely occurred in the present study. Decreases in ruminal branched-chain fatty acids during the challenge period also could be attributed to lower dietary protein concentrations as well as increased utilization of branched-chain fatty acids by microbes in response to increased fermentable energy supply.

Concentrations of ruminal lactate were undetectable before the SARA challenge and increased linearly ($P < 0.05$) with repeated challenges (Figure 3). Lactic acid concentrations were similar among diets and averaged 3.1, 4.3, and 9.8 mM for d 13, 14, and 15, respec-

Figure 4. Effect of induced subacute ruminal acidosis (SARA) challenge on ruminal acetate, propionate, butyrate, and branched chain VFA concentrations of cows fed a pellet containing 75% raw soybean hulls, 25% corn steep liquor (SHSL, DM basis, ○) or control (△).

Figure 5. Effect of induced subacute ruminal acidosis (SARA) challenge on ruminal acetate:propionate ratio (SEM = 0.29) of cows fed a pellet containing 75% raw soybean hulls, 25% corn steep liquor (SHSL, DM basis, ○) or control (△).

tively. Reductions in ruminal pH lead to a rumen microbial shift from lactic acid fermenters to lactic acid producers (Goad et al., 1998). Slight increases in lactic acid, usually < 10 mM, have been noted during induced SARA experiments (Harmon et al., 1985; Goad et al., 1998). Horn et al. (1979) indicated that increases in ruminal VFA concentrations depress ruminal pH during SARA more so than does the accumulation of lactic acid. Increasing concentrations of VFA in combination with increasing concentrations of lactic acid intensified the severity of SARA during the repeated challenges.

During the 2-d prechallenge collection phase, ruminal NH_3 concentrations (Figure 6) peaked 3 h after feeding, suggesting that protein degradation and fermentation exceeded the rate of carbohydrate fermentation. But within 6 to 9 h after feeding, NH_3 concentrations declined, indicating that NH_3 utilization exceeded production. Although prechallenge diets contained similar levels of protein (16%), cows fed SHSL tended ($P = 0.07$) to maintain higher ruminal NH_3 concentrations (8.2 vs. 11.5 mM for control and SHSL, respectively) throughout the trial. The protein of CSL is highly degradable by ruminal microorganisms both in vitro (Filho, 1999) and in vivo (Patterson et al., 2001). Contrary to Erfle et al. (1982) and Lana et al. (1998), NH_3 concentrations were not influenced by reduced ruminal pH, but percent CP was lower for challenge than for prechallenge diets despite changes in ruminal pH. Increases in carbohydrate fermentation would generate an increase in energy and carbon skeletons, which would increase the uptake of free NH_3 for the production of microbial cell protein. Furthermore, Goad et al. (1998) demonstrated that in-

Figure 6. Effect of induced subacute ruminal acidosis (SARA) challenge on ruminal ammonia, peptide N, and alpha-amino N concentrations of cows fed a pellet containing 75% raw soybean hulls, 25% corn steep liquor (SHSL, DM basis, ○) or control (△).

creases in ruminal acidity led to partial defaunation, which could reduce ruminal NH_3 concentrations (Veira, 1986). A review by Owens et al. (1998) indicated highly degradable protein sources, such as CSL, avert depressions in ruminal pH by increasing concentrations of alkaline NH_3 . Therefore, perhaps the higher NH_3 concentrations observed in cows consum-

ing SHSL contributed to their ability to cope with the induced SARA.

Although cows fed SHSL tended to have higher ruminal NH_3 concentrations, no differences were observed between diets for concentrations of peptide N and total ruminal α -amino N. However, inducing SARA resulted in higher ($P < 0.01$) concentrations of ruminal peptide N and total ruminal α -amino N (Figure 6). Concentrations of peptide N and total ruminal α -amino N were highest 3 h after feeding during the entire trial, but both were approximately twofold greater during SARA challenges, likely resulting from the force-feeding used to induce SARA. Concentrations of ruminal peptide N, NH_3 , and total α -amino N decreased at a similar rate during the 12 h after feeding throughout the trial. This is contradictory to Chen et al. (1987), who found the disappearance of ruminal peptide N to be greater than that of both NH_3 and soluble protein. Erfle et al. (1982) found that reducing ruminal pH from 7 to 5 resulted in an 88% reduction in bacterial protease activity, which subsequently reduced concentrations of NH_3 , total amino acids, and deaminative activity.

CONCLUSIONS

There was a tendency for cows fed SHSL to maintain higher ruminal NH_3 concentrations, but there were no other differences due to SHSL inclusion for the ruminal parameters measured. The lowered ruminal pH and elevated concentrations of VFA and lactate suggest the model used to induce SARA was successful. The partial replacement of alfalfa hay, corn silage, corn, and SBM by SHSL did not affect the observed responses to SARA challenges.

ACKNOWLEDGMENTS

Funding was provided by Minnesota Corn Processors, LLC, Marshall, MN and the Kansas Agricultural Experiment Station. The authors express appreciation to Cheryl K. Armendariz for laboratory assistance and personnel at the Kansas State University Dairy Teaching and Research Center for their contributions during the completion of these experiments.

REFERENCES

- Allison, M. J., and M. P. Bryant. 1963. Biosynthesis of branched-chain fatty acids by rumen bacteria. *Arch. Biochem. Biophys.* 101:269–277.
- Barker, S. B., and W. H. Summerson. 1941. The colorimetric determination of lactic acid in biological material. *J. Biol. Chem.* 138:535–554.
- Broderick, G. A., and J. H. Kang. 1980. Automated simultaneous determination of ammonia and total amino acids in ruminal fluid and in vitro media. *J. Dairy Sci.* 63:64–75.
- Chen, G., C. J. Sniffen, and J. B. Russell. 1987. Concentration and estimated flow of peptides from the rumen of dairy cattle: Effects of protein quality, protein solubility, and feeding frequency. *J. Dairy Sci.* 70:983–992.
- Clark, P. W., and L. E. Armentano. 1997. Replacement of alfalfa neutral detergent fiber with a combination of nonforage fiber sources. *J. Dairy Sci.* 80:675–680.
- Coblentz, W. K., I. E. O. Abdelgadir, R. C. Cochran, J. O. Fritz, W. H. Fick, K. C. Olson, and J. E. Turner. 1999. Degradability of forage proteins by in situ and in vitro enzymatic methods. *J. Dairy Sci.* 82:343–354.
- Cunningham, K. D., M. J. Cecava, and T. R. Johnson. 1993. Nutrient digestion, nitrogen, and amino acid flows in lactating cows fed soybean hulls in place of forage or concentrate. *J. Dairy Sci.* 76:3523–3535.
- DeFraen, J. M., J. E. Shirley, E. C. Titgemeyer, A. F. Park, and R. T. Ethington. 2001. Optimal inclusion level of a raw soybean hull-corn steep liquor pellet in diets for lactating dairy cows. *J. Dairy Sci.* 84(Suppl. 1):419. (Abstr.).
- Erfle, J. D., R. J. Boila, R. M. Teather, S. Mahadevan, and F. D. Sauer. 1982. Effect of pH on fermentation characteristics and protein degradation by rumen microorganisms in vitro. *J. Dairy Sci.* 65:1457–1464.
- Filho, C. C. R. 1999. Evaluation of modified condensed molasses solubles and corn steep liquor as nitrogen sources for rumen microbes in vitro and as sources of supplemental nitrogen for finishing cattle. M.S. Thesis, Iowa State University, Ames.
- Garleb, K. A., G. C. Fahey, Jr., S. M. Lewis, M. S. Kerley, and L. Montgomery. 1988. Chemical composition and digestibility of fiber fractions of certain byproduct feedstuffs fed to ruminants. *J. Anim. Sci.* 66:2650–2662.
- Goad, D. W., C. L. Goad, and T. G. Nagaraja. 1998. Ruminal microbial and fermentative changes associated with experimentally induced subacute acidosis in steers. *J. Anim. Sci.* 76:234–241.
- Harmon, D. L., R. A. Britton, R. L. Prior, and R. A. Stock. 1985. Net portal absorption of lactate and volatile fatty acids in steers experiencing glucose-induced acidosis or fed a 70% concentrate diet ad libitum. *J. Anim. Sci.* 60:560–569.
- Highfill, B. D., D. L. Boggs, H. E. Amos, and J. G. Crickman. 1987. Effects of high fiber energy supplements on fermentation characteristics and in vivo and in situ digestibilities of low-quality fescue hay. *J. Anim. Sci.* 65:224–234.
- Horn, G. W., J. L. Gordon, E. C. Prigge, and F. N. Owens. 1979. Dietary buffers and ruminal and blood parameters of subclinical lactic acidosis in steers. *J. Anim. Sci.* 48:683–691.
- Hull, S. R., B. Y. Yang, D. Venzke, K. Kulhavy, and R. Montgomery. 1996. Composition of corn steep water during steeping. *J. Agric. Food Chem.* 44:1857–1863.
- Jasaitis, D. K., J. E. Wohlt, and J. L. Evans. 1987. Influence of feed ion content on buffering capacity of ruminant feedstuffs in vitro. *J. Dairy Sci.* 70:1391–1403.
- Johnson, R. R., E. W. Klosterman, and O. G. Bentley. 1962. Energy value of lactic acid and corn steepwater and their effects on digestibility of ruminant rations. *J. Anim. Sci.* 21:887–891.
- Lana, R. P., J. B. Russell, and M. E. Van Amburgh. 1998. The role of pH in regulating ruminal methane and ammonia production. *J. Anim. Sci.* 76:2190–2196.
- Littell, R. C., G. A. Milliken, S. W. Walter, and R. D. Wolfinger. 1996. SAS systems for *Mixed Models*. SAS Institute, Inc., Cary, NC.
- Mertens, D. R., and J. R. Loften. 1980. The effect of starch on forage fiber digestion kinetics in vitro. *J. Dairy Sci.* 63:1437–1446.
- Nagaraja, T. G., M. L. Galyean, and N. A. Cole. 1998. Nutrition and disease. *Vet. Clin. North Am. Food Anim. Pract.* 14:257–275.
- National Research Council. 1988. *Nutrient Requirements of Dairy Cattle*. 6th rev. ed. Natl. Acad. Sci., Washington, DC.
- Owens, F. N., D. S. Secrist, W. J. Hill, and D. R. Gill. 1998. Acidosis in cattle: A review. *J. Anim. Sci.* 76:275–286.
- Patterson, T., T. Klopfenstein, D. J. Jordon, C. Wilson, R. Mass, and R. Stock. 2001. Undegradable intake protein content of corn steep compared to soybean meal. *Univ. Neb. Beef Cattle Rep.*, MP 76-A, p. 37–38.

- Roe, M. B., and C. J. Sniffen. 1990. Techniques for measuring protein fractions in feedstuffs. Pages 81–88 in *Proc. Cornell Nutr. Conf. Feed Manuf.*, Cornell Univ., Ithaca, NY.
- Sarwar, M., J. L. Firkins, and M. L. Eastridge. 1991. Effect of replacing neutral detergent fiber of forage with soyhulls and corn gluten feed for dairy heifers. *J. Dairy Sci.* 74:1006–1017.
- Sarwar, M., J. L. Firkins, and M. L. Eastridge. 1992. Effects of varying forage and concentrate carbohydrates on nutrient digestibilities and milk production by dairy cows. *J. Dairy Sci.* 75:1533–1542.
- SAS User's Guide: Statistics, Version 6 Third Edition. 1990. SAS Inst., Inc., Cary, NC.
- Sutton, J. D. 1989. Altering milk composition by feeding. *J. Dairy Sci.* 72:2801–2814.
- Van Soest, P. J., and D. G. Fox. 1992. Discounts for net energy and protein. Pages 40–68 in *Proc. Cornell Nutr. Conf. Feed Manuf.*, Cornell Univ., Ithaca, NY.
- Varga, G. A., E. M. Meisterling, R. A. Dailey, and W. H. Hoover. 1984. Effect of low and high fill diets on dry matter intake, milk production, and reproductive performance during early lactation. *J. Dairy Sci.* 67:1240–1248.
- Veira, D. M. 1986. The role of ciliate protozoa in nutrition of the ruminant. *J. Anim. Sci.* 63:1547–1560.
- Wagner, J. J., K. S. Lusby, and G. W. Horn. 1983. Condensed molasses solubles, corn steep liquor, and fermented ammoniated condensed whey as protein sources for beef cattle grazing dormant native range. *J. Anim. Sci.* 57:542–552.
- Weidner, S. J., and R. J. Grant. 1994a. Altered ruminal mat consistency by high percentages of soybean hulls fed to lactating dairy cows. *J. Dairy Sci.* 77:522–532.
- Weidner, S. J., and R. J. Grant. 1994b. Soyhulls as a replacement for forage fiber in diets for lactating dairy cows. *J. Dairy Sci.* 77:513–521.
- Weiss, W. P., H. R. Conrad, and N. R. St. Pierre. 1992. A theoretically-based model for predicting total digestible nutrient values for forages and concentrates. *Anim. Feed Sci. Tech.* 39:95–110.
- Wessels, R. H., E. C. Titgemeyer, C. K. Armendariz, and G. St. Jean. 1996. Lasalocid effects on ruminal degradation of protein and postruminal supply of amino acids in Holstein steers. *J. Dairy Sci.* 79:1802–1808.
- Wohlt, J. E., D. K. Jasaitis, and J. L. Evans. 1987. Use of acid and base titrations to evaluate the buffering capacity of ruminant feedstuffs in vitro. *J. Dairy Sci.* 70:1465–1470.