A BUFFER VALUE INDEX TO EVALUATE THE INFLUENCE OF DIETARY BUFFERS ON DAIRY COWS

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Story in Brief

We developed a buffer value index to simultaneously evaluate alterations in ruminal fluid pH and buffering capacity caused by dietary buffers. It was evaluated using ruminal fluid from four lactating Holstein cows fed either sorghum silage or alfalfa hay in high or low concentrate diets. Ruminal fluid pH was lower for high concentrate and alfalfa based diets; buffering capacity between pH 5 and 7 was greater for high concentrate diets, but buffering capacity was not affected by forage type. Effects of adding buffers to the ruminal fluid on the buffer value index was measured. The buffer value index was highest for sodium bicarbonate, followed by sodium sesquicarbonate, a multielement buffer and the unbuffered control. Dietary buffers increased both ruminal fluid pH and buffering capacity; both of these responses are beneficial. Because the buffer value index can account for alterations in both pH and buffering capacity, we believe that it more precisely evaluates diet-induced changes in ruminal acid-base status, and should be valuable to appraise dietary buffers.

(Key Words: Buffers, Index, Acid-Base, Dairy Cow.)

Introduction

Dietary buffers can reduce the detrimental effects of acid-producing, high concentrate diets fed to dairy cows. Typically, the efficacy of a specific buffer is determined by evaluating its influence on ruminal fluid pH. In addition to raising ruminal fluid pH, buffers increase the buffering capacity (resistance to change in pH), and thereby provide a more stable environment for growth of ruminal microbes.

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At present, no model accounts for alterations in both ruminal pH and buffering capacity (BC) caused by dietary buffers. Therefore, the objective of our study was to develop a buffer value index (BVI). This index was used to characterize acid-base effects of dietary buffers on ruminal fluid, and to measure pH and BC responses to $NaHCO_3$, sodium sesquicarbonate (SSC; Alkaten, Church & Dwight Co, Inc., Princeton, NJ), and a multielement buffer (MEB; Pitman-Moore, Inc., Mundelein, IL).

Materials and Methods

Four ruminally fistulated, lactating Holstein cows were assigned randomly to a 2 x 2 factorial arrangement of treatments in a 4 x 4 Latin square with 2-wk experimental periods. Treatments were total mixed diets (Table 1) based upon either sorghum silage or alfalfa hay, and containing either a high or low amount of concentrate. Cows were fed twice daily and allowed ad libitum access to their feed; refusals were recorded daily.

Milk yield was measured daily and milk samples were collected weekly throughout the study. On the morning of the last day of each experimental period, at 5 h postfeeding, approximately 1.8 L of ruminal fluid were collected from each cow via fistula from the ventral sac of the rumen. Ruminal fluid was collected at 5 h postfeeding to ensure that the fluid would have a high acid content; in this study, our objective was to observe the physical effects of acidic ruminal fluid on the dissolution of several buffers, rather than to imitate ruminal fermentation. Ruminal fluid was frozen for incubation at a lower time.

Upon thawing, 70 ml ruminal fluid were dispensed into 125-ml Erlenmeyer flasks equipped with Bunsen valves; 0 or .5 g of either $NaHCO_3$, SSC, or MEB was added to each flask; each flask was placed in a shaking water bath (39° C) for 1, 2, 3, 4, or 5 h. After incubation, ruminal fluid pH and BC were determined.

To calculate the BVI of the ruminal fluid, a standard pH (STPH) of 6 and standard BC (STBC) of 50 meq / L were employed as a base point (BVI = 100); these values were selected as being typical from previous studies. The BVI was calculated from ruminal fluid sample pH (SAPH) and BC (SABC; meq / L) by the following formula:

BVI = 100 + 10 x ((((antilog10 (- STPH)) - (antilog10 (- SAPH))) / antilog10 (- STPH)) + ((SABC - STBC) / STBC))

The BVI increases as ruminal fluid H^+ decreases or ruminal fluid BC increases; each of these responses should be beneficial to high-producing dairy

Table 1. Ingredient and nutrient composition of experimental diets.

Ingredient	Diet			
	High grain + sorghum	High grain + alfalfa	Low grain + sorghum	Low grain + alfalfa
	(% DM)			
Sorghum silage	36.09	4.03	54.08	6.03
Alfalfa hay	4.01	36.12	6.00	54.01
Corn grain, ground	36.82	48.91	15.50	33.27
Soybean meal, 44% CP	20.69	9.42	22.14	5.28
Limestone	.88	...	.66	...
Dicalcium phosphate	.64	.64	.85	.75
Dynamate[a]	.43	.32	.32	.11
Trace mineralized salt	.44	.44	.44	.44
Magnesium oxide	...	.11	...	.11
Nutrient[b]				
DM	53.65	82.90	44.85	80.44
CP	16.97	17.06	17.04	17.13
NEL,[c] Mcal/kg	1.68	1.72	1.57	1.61
ADF	18.45	14.46	25.57	19.55
NDF	27.58	22.45	36.43	28.66
Ca	.70	.76	.77	1.05
P	.44	.44	.46	.44
Mg	.29	.30	.31	.29
Na	.23	.25	.23	.27
K	1.02	1.39	1.15	1.68
Cl	.36	.43	.38	.48
S	.27	.29	.25	.27

[a]Double sulfate of K and Mg.

[b]Nutrient content calculated from nutrient analysis of sorghum silage and alfalfa hay prior to the study; tabular values were utilized for shelled corn, soybean meal and mineral supplements.

[c]Calculated from ADF.

cows. Conversely, an increase in H^+ or a reduction in BC lowers BVI. Consolidating the effects of dietary buffers on ruminal fluid H^+ and BC into a single, numeric value allows one to evaluate the overall effects of dietary buffers on the rumen more completely.

Results and Discussion

Animal Performance

Dry matter intake, milk yield, and milk composition (Table 2) were not affected by forage or concentrate content of the diets, although intake was somewhat lower ($P = .073$) for alfalfa diets. No explanation for this is apparent. Milk yield and dry matter intake were low on all diets, reflecting the advanced stage of lactation of the cows (285 days in milk).

In Vitro Incubation of Ruminal Fluid

Diet Effects. Because pH, BC and BVI responses were not markedly altered by incubation time, incubations for 1 to 5 hours within an animal, diet and buffer were averaged and utilized as a single value in all statistical analyses. Table 2 presents effects of diet on ruminal fluid acid-base status. Initial pH, which represents the pH of the ruminal fluid after incubation, tended to be lower in cows fed the high concentrate diets, potentially the result of rapid fermentation of readily-available carbohydrates and less saliva production. Initial pH tended to be higher for sorghum silage versus alfalfa-based diets. Ruminal fluid H^+ (Table 2) tended to be highest for high concentrate diets ($P = .10$).

Ruminal fluid BC (Table 2) was higher for high versus low concentrate diets. In our study, dietary forage source had no effect on BC of the ruminal fluid. Jasaitis et al. (1987) reported that the BC of alfalfa hay exceeded that of corn silage; they did not measure BC of sorghum silage. Dietary BC may or may not alter ruminal fluid BC.

Although ruminal fluid from the low concentrate diets in our study had lower acidity than that from the high concentrate diets, BC also was lower; hence, BVI of the ruminal fluid was similar (NS; Table 2) for high versus low concentrate diets. Ruminal fluid from cows consuming sorghum silage-based diets had a somewhat higher BVI than that from alfalfa diets; because ruminal fluid BC was similar for the two types of diets, the difference in BVI was a result of the lower ruminal fluid H^+ for the sorghum diets.

Buffer Effects. Our evaluation of buffer effects on ruminal fluid acid-base status are presented as mean responses across diets. Initial pH of ruminal fluid

Table 2. Least squares mean DMI, milk yield and milk composition, and ruminal fluid acid-base status as affected by diet.

	High grain + sorghum	High grain + alfalfa	Low grain + sorghum	Low grain + alfalfa	SE[a]	Grain		Forage			
						High	Low	Sorghum	Alfalfa	Effect	*P*
DMI, kg	18.3	15.8	17.0	15.2	1.0	17.0	16.1	17.6	15.5	Forage	.073
Milk yield, kg	12.5	11.5	11.0	9.9	.8	12.0	10.4	11.7	10.7	NS[b]	
Fat, %	3.45	3.55	3.54	3.73	.23	3.50	3.64	3.50	3.64	NS	
Protein, %	3.26	3.32	3.17	3.17	.17	09	3.29	33.21	3.25	NS	
Ruminal fluid											
pH	7.35	7.14	7.65	7.72		7.25	7.68	7.50	7.43		
H^+ neq/L	187	273	67	103	73	230	85	127	188	Grain	.096
Buffering capacity, meq/L	85.7	85.3	81.6	81.3	3.8	85.5	81.5	83.7	83.3	NS	
BVI[c]	115.3	114.4	115.7	115.2	.9	114.8	115.4	115.5	114.8	NS	

[a]SE of class means = SE of treatment means / 1.414.
[b]$P > .10$.
[c]Buffer value index.

from flasks incubated with various buffers is presented in Figure 1A. Ruminal fluid pH tended to be increased by the addition of each buffer; this response was most marked for SSC, intermediate for $NaHCO_3$, and lowest for MEB. However, analysis of ruminal fluid H^+ (Figure 1B) revealed that $NaHCO_3$ and SSC reduced acidity similarly (NS).

Buffering capacity of the ruminal fluid (Figure 1C) was highest for $NaHCO_3$, intermediate for SSC and lowest for MEB and control, which had BC that did not differ. Previous observations that SSC has a higher buffering potential than $NaHCO_3$ (Solorzano et al., 1989) have evolved from analyses of BC across a non-physiological pH range.

Comparison of BVI for various buffers is shown in Figure 1D. Ruminal fluid BVI was highest for $NaHCO_3$, followed by SSC, MEB and the control. Because H^+ was not significantly different between $NaHCO_3$ and SSC, the increased BVI for $NaHCO_3$ is attributable solely to its higher BC. Buffer value index for MEB was higher than for control because MEB reduced H^+; however, BC was not affected (NS) by this buffer. In the present study, ruminal fluid was incubated with buffers for only 5 h. Longer-term studies in our laboratory (unpublished) indicate that MEB releases BC most effectively when incubated for longer than 12 h; hence, its BVI ranking might have been greater with a longer incubation interval.

The BVI credits buffers for increasing pH and for increasing the BC of ruminal fluid; conversely, BVI is lowered by reductions in either of these variables. Accordingly, two ruminal fluid samples that have similar BVI potentially could have vastly different pH or different BC; however, to preserve this similarity in BVI, a reduction in one variable (pH or BC) must be offset by an increase in the other. A high ruminal fluid BVI can result from buffering compounds that increase ruminal fluid pH, increase ruminal fluid BC, or increase both of these variables.

Because BVI appraises both pH and BC components of a compound's ability to withstand an acid challenge, it is useful as an indicator of the influence of dietary buffers on ruminal fluid acid-base status or stability, or both. This index may allow more accurate evaluation of the efficacy of commercially-available buffers, thereby providing dairy farmers with information that will facilitate a more informed choice in the selection of dietary buffers for formulating his diets.

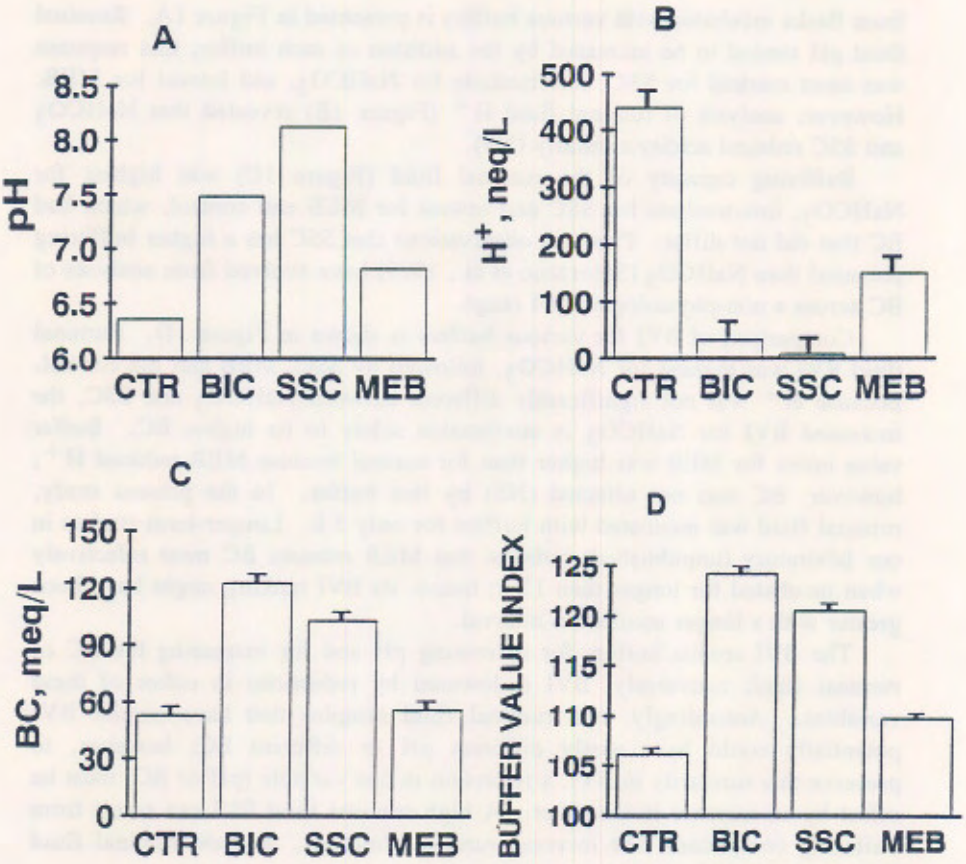

Figure Legends

Figure 1. Buffer addition vs. ruminal fluid pH (Panel A), ruminal fluid hydrogen ion concentration (Panel B), ruminal fluid buffering capacity (Panel C) and ruminal fluid buffer value index (Panel D) averaged across 5 h incubation. CTR = control, incubation with no buffer; BIC = incubation with sodium bicarbonate; SSC = incubation with sodium sesquicarbonate; MEB = incubation with a multielement buffer.

Literature Cited

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