

Feeding Complete Feed Containing Different Acidogenic Value and Effective Fiber Affect Rumen Acidosis Depression

(Pemberian Ransum Komplit dengan Kandungan Acidogenic Value dan Kandungan Serat Efektif Berbeda Berpengaruh terhadap Depresi Rumen Acidosis)

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ABSTRAK: Tujuan dari penelitian adalah untuk mengevaluasi pengaruh pemberian ransum komplit (*complete feed*, CF) dengan kandungan acidogenic value (AV) dan physically effective Neutral Detergent Fiber (peNDF) berbeda, terhadap tingkat depresi rumen acidosis pada sapi perah. Empat ransum komplit (CF) iso-energi dan iso-protein yang diformulasi dari bahan konsentrat dengan kandungan AV berbeda (AV rendah; LA = 9 mg Ca g⁻¹ DM atau AV tinggi; HA = 6,5 mg Ca g⁻¹ DM), dicampur dengan silase jagung dan alfalfa yang di cacah dengan ukuran partikel berbeda (kasar : CS; dan lembut : FS). Rataan panjang geometris partikel (X_{gm}) CS = 12,8 mm, FS = 10,2 mm. Perbedaan ukuran partikel hijauan menghasilkan peNDF_{>1.18} yang berbeda. Empat ekor sapi fistula laktasi dibagi secara acak untuk memperoleh satu dari 4 ransum percobaan dalam rancangan faktorial (2 x 2) (HACS, LACS, HAFS, dan LAFS). Rumen acidosis dievaluasi dengan pengukuran pH rumen secara kontinyu selama 4 hari berturut turut. Semua ransum percobaan menyebabkan sub-acute rumen acidosis (SARA) dengan tingkat depresi pH rumen yang berbeda. Tingkat depresi rumen acidosis dievaluasi dengan waktu yang di butuhkan ketika pH rumen dibawah atau pada saat pH rumen 5,6 dan 5,8. Peningkatan kandungan AV meningkatkan depresi rumen acidosis, yang ditandai dengan perpanjangan waktu selama pH rumen dibawah 5,6 (135.1 vs. 236.7 min d⁻¹; LA vs. HA, berturut-turut) dan selama pH rumen dibawah pH 5.8 (290.0 vs. 480.6 min d⁻¹; LA vs. HA, berturut-turut). Peningkatan peNDF_{>1.18} (CS) mampu memperpendek waktu selama pH rumen 5.8 (290.5 vs. 194.9 min/d) untuk sapi yang diberi pakan komplit dengan AV tinggi (HA), tetapi tidak untuk sapi yang diberi CF dengan AV rendah (LA). Peningkatan peNDF ransum dapat membantu memperkecil depresi rumen acidosis ketika diberi pakan CF dengan AV tinggi. Oleh sebab itu, AV dan peNDF dapat digunakan untuk memperbaiki formulasi ransum untuk memperkecil depresi rumen acidosis.

Kata Kunci: Complete feed (CF), Acidogenic Value (AV), peNDF, pH rumen, rumen acidosis

Introduction

Rumen acidosis is a common metabolic problem in dairy cattle (Nocek, 1997), associated with the rate and extent of acid production from feed fermentation. The severity of ruminal acidosis in cattle is variable and ranges from acute to subacute or chronic (Owens *et al.*, 1998; Kleen *et al.*, 2003). In dairy operations, sub-acute acidosis (SARA) is more common than acute acidosis. Feeding a diet high in ruminally fermentable carbohydrate (RFC) and/or low in effective fibre causes the initial rumen insult (Armentano and Pereira, 1997). SARA is identified by a daily repeated period of depressed rumen pH between 5.2 and 5.6 (Cooper *et al.*, 1995; Cooper and Klopfenstein, 1996; Owens *et al.*, 1998; Cumby *et al.*, 2001). In spite of this, the length of time per day

when ruminal pH is below 5.6 (Keunen *et al.*, 2002) or below 5.8 (Krause *et al.*, 2002b; Krause and Combs, 2003) was a more important determinant of rumen acidosis depression than the mean daily ruminal pH. The clinical signs of SARA are not easily observed, but it can decrease feed intake (Garret *et al.*, 1999). Animals suffering from SARA remain alert, but have transient anorexia, depression and dehydration (Underwood, 1992).

Rumen acidosis is related to the amount of acid produced as feed is fermented and the ability of the feed to encourage chewing and production of salivary buffers. The possibility of alleviating ruminal acidosis relates to both the amount of acid produced from fermentation of feed and the ability of the feed to stimulate chewing and production of salivary buffers (Mertens 1997). Rustomo *et al.* (2006a) evaluated the acidogenic value (AV) of feeds using an in vitro laboratory technique. The AV varied with protein, starch, NFC and fiber contents of feedstuffs. Physically effective NDF (peNDF) has

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been defined as the fraction of feed that stimulates chewing and saliva production (Mertens, 1997). Zebeli *et al.* (2006) reported that $\text{peNDF}_{>1.18}$ was a better parameter to predict ruminal pH ($R^2 = 0.67$) than $\text{peNDF}_{>8}$ ($R^2 = 0.27$). The $\text{peNDF}_{>1.18}$ also provide better parameters to evaluate fiber effectiveness of rations rather than merely use dietary NDF or forage NDF. The objective of the present study was to evaluate the effects of, and the interaction between, level of feed AV and $\text{peNDF}_{>1.18}$ on rumen acidosis depression in dairy cows.

Research Methods

Animals and Feed Intake. Four multiparous fistulated Holstein dairy cows (114 ± 14 DIM, and 600 ± 66 kg live weight) were used in this trial. The cows were fed twice daily at 0900 and 1300 h in equal portions for *ad libitum* intake (10% refusals). Feed intake was recorded daily, and the animals had unlimited access to fresh water. Feed and ort samples were taken 3 times per week and stored at -20°C for later analysis. The DM of the feeds and Orts were determined by oven drying at 60°C for 48 h (AOAC, 1990).

Feed Analysis. The AV of feeds (mg Ca g^{-1} DM) were analyzed as described by Rustomo *et al.* (2006a). The chemical compositions of feeds were determined using standard AOAC (1990). Organic matter was assessed by ashing at 500°C for 16 h and CP, soluble protein and non-protein nitrogen was determined using the macro-Kjeldahl. Starch was analyzed using starch hydrolysis method (Hall, 2000), Ca and P using spectroscopy, ether extract, ADF and lignin using method of AOAC, (1990), NDF (AOAC, 2002) using A-3306 alpha amylase (Sigma-Aldrich, St. Louis, MO). Non-fiber carbohydrates (NFC) were calculated as $\text{NFC} = 100 - (\% \text{NDF} + \% \text{CP} + \% \text{Fat} + \% \text{Ash})$.

Physically Effective NDF (peNDF) Analysis. The physically effective NDF ($\text{peNDF}_{>1.18}$) was estimated using the total NDF content of the feed multiplied by the physical effectiveness factor ($\text{pef}_{>1.18}$). The pef of particles > 1.18 mm ($\text{pef}_{>1.18}$) was determined using the proportion of DM of particles retained on the top-, middle- and bottom- screen of the PSPS (Heinrichs and Kononoff, 2002; Kononoff and Heinrichs, 2003a). The particle sizes of CF was assessed by the new compact Penn State Particle Size Separator (PSPS; C24682N, Nasco 3-sieves Forage Particle

Separator, Fort Atkinson, Wisconsin) as described by Kononoff *et al.* (2003a). All feed samples were sieved in triplicate. The geometric mean (X_{gm}) and standard deviation (S_{gm}) (Assessed by Standard S424, ASAE, 2001), and the $\text{peNDF}_{>1.18}$ analysis are presented in Table 3.

Experimental Design. The feeding experiment was conducted as a 4×4 Latin square with a 2×2 factorial treatment arrangement, with the duration of each period was 3 wk (14 d of adaptation and 7 d of data collection). Feed ingredient AV was used to formulate two isoenergetic ($\text{NE}_L = 1.5 \pm 0.01$ Mcal kg^{-1}) and isonitrogenous ($\text{CP} = 17.4 \pm 0.1$ % DM) concentrate diets (low AV, LA vs. high AV, HA). All diets were formulated to meet or exceed the requirements of a 620 kg multiparous cow producing 30 kg of milk per day according to the Cornell-Penn-Miner Dairy model version 3.0. Diets were fed as a CF with forage to concentrate ratio of 50:50. Two levels of forage particle size (CS and FS) were combined with the 2 levels of concentrate AV (HA and LA) to prepare 4 complete feed (CF) or total mix ration (TMR) in a data ranger (American Calan, Northwood, NH); HACS, HA concentrate + coarse silage; HAFS, HA concentrate + fine silage; LACS, LA concentrate + coarse silage and LAFS, LA concentrate + fine silage. Alfalfa haylage and corn silage (the theoretical length of cut 1.3 and 1.9 cm, respectively), provided the coarse forage of the diets (CS). The finely chopped forage (FS) was obtained by rechopping CS (1600 rpm for 36 min in a mixer; Taylor Model # 1350, Orton, ON). The ingredients composition of the concentrate are shown in Table 1 and dietary composition of the CF are presented in Table 2.

Ruminal pH Measurements. Ruminal pH was measured continuously every minute for 4 d in each period using pH electrode (AlZahal *et al.* 2006). The pH probe was placed into the anterior region of the ventral sac of the rumen with a weight of 0.5 kg. The probe was connected to a data logger (pH Temp101, Monarch Instrument, Amherst, NH). The position of the pH electrode was examined 3 times each day. Electrodes and the pH transmitter were calibrated at recording period using standard pH 4 – 7 (Fisher Scientific, Fairlawn, NJ). Rumen fluid was also sampled 3 times each day for pH measurement using a pH meter (pH 310, Oakton Instruments, Vernon Hills, IL) to verify the accuracy of continuous ruminal pH recordings. The daily ruminal pH data were recorded

using a data recording software (version 2.0, Monarch Instruments, Amherst, NH), and the pH data were summarized for each 24 h period by calculating the minimum, mean pH, and the amount of time below or at pH 5.6 and 5.8.

Table 1. Ingredient composition (% DM) and AV (mg Ca g⁻¹ feed DM) of the concentrate

Ingredients	Treatments ¹			
	HACS	HAFS	LACS	LAFS
Barley	24.20	24.20	-	-
Wheat	24.40	24.40	-	-
Oats	-	-	21.60	21.60
Wheat bran	-	-	46.10	46.10
Roasted soybeans	16.30	16.30	-	-
Canola meal	16.30	16.30	-	-
Corn gluten meal	-	-	9.90	9.90
Fish meal	-	-	2.90	2.90
Soybean meal	14.90	14.90	14.80	14.80
Tallow	-	-	1.58	1.58
Salt	0.99	0.99	0.59	0.59
CaCO ₃ powder	1.29	1.29	2.18	2.18
Dicalcium phosphate	1.29	1.29	-	-
Selenium	0.30	0.30	0.30	0.30
Mineral and vitamin premix	0.10	0.10	0.10	0.10

¹Treatments: HACS = High-AV concentrate and coarse silage, HAFS = High-AV concentrate and fine silage, LACS = Low-AV concentrate and coarse silage, LAFS = Low-AV concentrate and fine silage.

Table 2. Dietary composition, chemical analysis and AV (mg Ca g⁻¹ feed DM) of the complete feed (CF)

Ingredients	Treatments ¹			
	HACS	HAFS	LACS	LAFS
<i>Ingredients (%; DM basis)</i>				
Concentrates	50.10	50.10	50.10	50.10
Corn silage ²	26.80	26.80	26.80	26.80
Alfalfa silage ³	23.10	23.10	23.10	23.10
Dry matter (%)	44.40	44.20	44.70	44.70
Organic matter (% of DM)	92.70	91.70	92.80	92.80
NE _L (Mcal kg ⁻¹)	1.50	1.50	1.50	1.50
<i>Composition (%; DM basis)</i>				
Crude protein, % of DM	17.60	17.60	17.10	17.30
Soluble protein, % of DM	5.00	5.00	4.50	4.70
Undegradable protein, % of CP	35.00	35.90	36.90	36.60
NDF, % of DM	41.70	42.60	44.00	44.00
ADF, % of DM	26.60	25.50	26.30	26.10
NFC, % of DM	29.90	28.70	28.60	27.90
Starch, % of DM	15.60	15.40	14.20	13.80
Calcium, % of DM	0.70	0.70	0.70	0.70
Phosphorus, % of DM	0.50	0.50	0.50	0.50
Potassium, % of DM	1.80	1.80	1.80	1.80
Magnesium, % of DM	0.20	0.20	0.30	0.30
Sodium, % of DM	0.20	0.20	0.10	0.10
AV, mg Ca g ⁻¹ DM	10.00	10.00	8.70	8.70

¹Treatments: HACS = High-AV concentrate and coarse silage, HAFS = High-AV concentrate and fine silage, LACS = Low-AV concentrate and coarse silage, LAFS = Low-AV concentrate and fine silage.

²DM, 31.00 %; CP, 7.10 %; ADF, 27.90 %; NDF, 47.00 %; starch, 24.60 % and NFC, 39.50 %.

³DM, 41.30 %; CP, 16.30 %; ADF, 39.90 %; NDF, 55.10 %; starch, 0.40 % and NFC, 16.20 %.

Statistical Analysis. Data on the response variables were analyzed using PROC MIXED of SAS® (v. 9.1; SAS Institute Inc., 2004) using the model: $Y_{ijkl} = \mu + C_i + P_j + A_k + F_l + (A \times F)_{kl} + \epsilon_{ijkl}$; where Y_{ijkl} = the dependent variable, μ = overall mean, C_i = effect of cow ($i = 1, 2, 3, 4$), P_j = effect of period ($j = 1, 2, 3, 4$), A_k = effect of AV ($k = 1, 2$), F_l = effect of peNDF ($l = 1, 2$), $(A \times F)_{kl}$ = the effect of interaction of A_k and F_l , and ϵ_{ijkl} = random residual error. The effects of AV and peNDF_{>1.18} were analyzed as fixed effects. For the repeated measurements of continuous ruminal pH data, day of sampling was analyzed as a fixed effect with repeated measurement.

Results and Discussion

Result of peNDF analysis are shown in Table 3. The geometric mean length of all diets was greater than the minimum of 6.4 mm that has been proposed to reduce rumination (Woodford *et al.*, 1986). Rechopping forage reduced the geometric mean particle size and peNDF_{>1.18} of FS CF. The peNDF_{>1.18} was 40.4 vs. 38.5% DM for CS and FS diets, respectively. Kononoff and Heinrichs, (2003a) suggested that measuring peNDF_{>1.18} using PSPS is more reasonable parameter to assess physically effective fiber in the CF than that of peNDF_{>8}, due to the large portion of concentrate that passes through an 8 mm screen.

Table 3. Particle size, physical effectiveness factor (pef_{>1.18}) and peNDF_{>1.18} (%DM) of Complete Fed (CF)

Dependent variable	Treatments ¹				P value		
	HACS	HAFS	LACS	LAFS	SEM ²	AV ³	PS ⁴
X_{gm} , mm ⁵	9.90	7.50	9.70	7.60	0.09	0.60	<0.01
S_{gm} , mm ⁶	2.60	2.90	2.70	2.80	0.03	0.57	<0.01
NDF, % DM	41.70	42.60	44.00	44.00	0.77	0.02	0.17
pef _{>1.18} ⁷	0.94	0.89	0.94	0.89	0.02	0.17	<0.01
peNDF _{>1.18} ⁸	39.50	37.80	41.20	39.20	0.40	0.01	<0.01

¹Treatments: HACS = high acidogenic value concentrate, coarse forage;

HAFS = high acidogenic value concentrate, fine forage;

LACS = low acidogenic value concentrate, coarse forage;

LAFS = low acidogenic value concentrate, fine forage.

²SEM = Standard error of measurement (n = 12).

³AV = Acidogenic value of the diet.

⁴PS = Particle size of the diet.

⁵ X_{gm} = Geometric mean length as calculated by the ASAE (2001).

⁶ S_{gm} = Standard deviation as calculated by the ASAE (2001).

⁷pef_{>1.18} = physical effectiveness factor measured as the proportion of DM retained on top-, middle- and bottom- screen.

⁸peNDF_{>1.18} = physically effective NDF >1.18 mm = pef_{>1.18} multiplied by NDF content of TMR.

All diets resulted in similar pattern of ruminal pH changes during the day, which was related to feed intake. The ruminal pH declined after morning feeding and continuously depressed 8 h after afternoon feeding, then gradually increased and returned to normal pH (>6.0) over night (Figure 1).

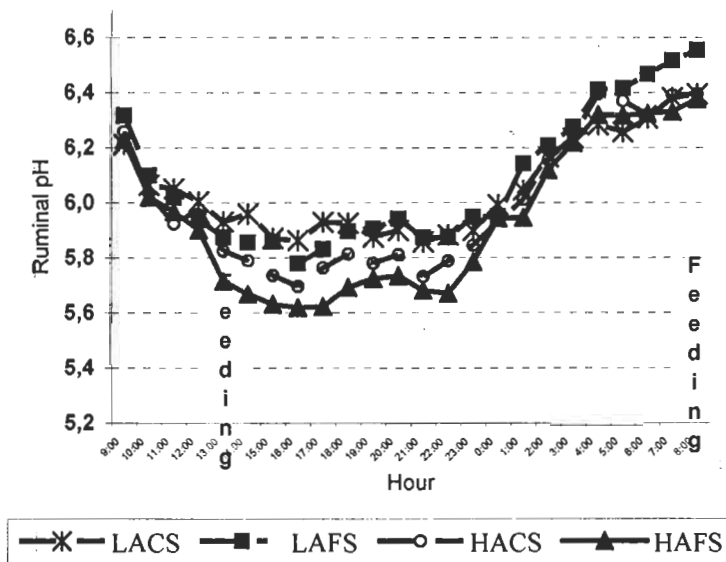


Figure 1. Daily Ruminal pH Changes of Experimental Cow Measured as Average Hourly Measurement of 4 Days Ruminal pH Readings.

The nadir of ruminal pH was attained at approximately 4 - 5 h after afternoon feeding. Although all diets resulted in a decreased ruminal pH or rumen acidosis, the rate and extent of rumen acidosis depression after morning feeding (Figure 2a) and afternoon feeding (Figure 2b) increased with increasing AV of CF, and with decreasing $\text{peNDF}_{>1.18}$ of CF. As expected, the rate of pH depression after morning feeding was highest for HAFS and lowest for LACS. The rumen acidosis depression was prolonged after afternoon feeding. During the day, the HAFS cows spent approximately 9 h per day at ruminal pH below 5.8, as compared to only approximately 4 h per day for LACS cows. There was a tendency that HAFS cows maintained a sub-optimum ruminal pH (< 5.8) longer than HACS cows and the LAFS cows maintained a sub-optimum ruminal pH (< 5.8) longer than LACS cows (Figure 2b). These results indicate that at the same level of concentrates AV, reducing $\text{peNDF}_{>1.18}$ resulted in a tendency of prolonged time spent at sub-optimal pH (< 5.8) and decreased time at the optimal pH (> 6.0). The trend in a decreased ruminal pH and an extended time spent at sub-optimum ruminal pH (< 5.8) due to increasing AV agree with the ruminal pH changes in *in vitro* study (Rustomo *et al.*, 2006a) as well as in *in vivo* study (Rustomo *et al.*, 2006b). Additionally, the tendency in an additional depression of ruminal pH due to decreasing $\text{peNDF}_{>1.18}$, likely reflected the

additional acid-load derived from feed fermentation of a lower $\text{peNDF}_{>1.18}$ (Table 4).

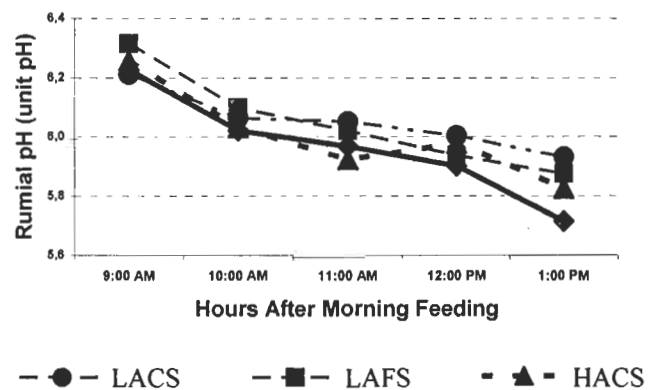


Figure 2a. Average Hourly Ruminal pH Changes Five Hours After Morning Feeding

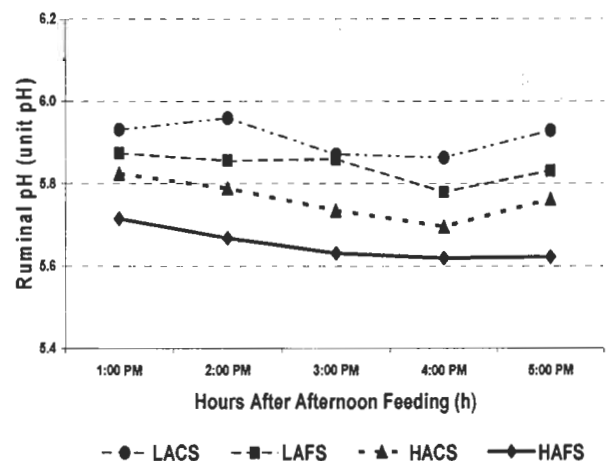


Figure 2b. Average Hourly Ruminal pH Changes Five Hours After Afternoon Feeding

The effects of dietary treatments on ruminal pH are presented in Table 4. Increasing concentrate AV decreased mean pH (from 6.07 to 5.97) and minimum pH (from 5.49 to 5.34). Whereas increasing $\text{peNDF}_{>1.18}$ did not affect ruminal pH changes. The results of rumen acidosis depressions due to feeding CF of different AV agree with the previous study of Rustomo *et al.* (2006b), where increasing concentrate AV increased time spent below pH 5.6 or below 5.8 by 2-4 h d^{-1} . Krause *et al.* (2002b) and Krause and Combs (2003) found that increasing dietary fermentability also increased time spent below pH 5.8. Based on time below pH 5.6 or 5.8, all cows used in the current study suffered sub acute rumen acidosis (SARA); however the SARA depression in HA cows was more severe than those in LA cows. Increasing concentrate AV increased time spent below pH 5.6 and 5.8 for

Table 4. Effect of acidogenic value of concentrate and forage particle size on mean-, minimum-, maximum-ruminal pH, time below pH 5.0 to 6.8 (min d⁻¹), DMI (Kg d⁻¹) and Acid Load

Dependent variable	Treatments ¹					P value		
	HACS	HAFS	LACS	LAFS	SEM ²	AV ³	peNDF ⁴	AV x peNDF
Mean ruminal pH,	6.01 ^a	5.94 ^a	6.05 ^{ab}	6.08 ^b	0.03	0.01	0.50	0.13
Minimum ruminal pH	5.38 ^a	5.29 ^a	5.49 ^{ab}	5.48 ^b	0.04	0.004	0.27	0.40
Time below pH 5.6	227.02	246.42	129.19	140.94	40.09	0.02	0.70	0.92
Time below pH 5.8	423.55 ^a	537.67 ^a	284.00 ^b	296.00 ^b	54.86	0.003	0.26	0.37
DMI	21.14	21.21	21.58	22.25	0.60	0.26	0.56	0.63
Acid load ⁵	211.40 ^a	212.10 ^a	187.75 ^b	193.54 ^{ab}	5.40	0.01	0.57	0.65

^{a-d} Means within a row with different superscripts differ ($P < 0.05$);

¹Treatments; HACS = high acidogenic value concentrate, coarse forage; HAFS = high acidogenic value concentrate, fine forage; LACS = low acidogenic value concentrate, coarse forage; LAFS = low acidogenic value concentrate, fine forage.

²SEM = Standard error of measurements ($n = 16$);

³AV = Acidogenic value of the diet;

⁴peNDF = peNDF of the diet

⁵Acid load = Acidogenic value of feed multiplied by DMI.

approximately 2 h d⁻¹ and 3 h d⁻¹, respectively. The depression in ruminal pH in the first 5 h after morning feeding (Figure 2a) was likely due to increased rumen acid load from the excessive accumulation of VFA rather than lactic acid (Oetzel, 2000). The acid load within the rumen are generated from feedstuffs as end products of organic matter fermentation by rumen microbes (Allen, 1997). In normal feeding conditions, VFA do not increase in the rumen at high enough concentration to depress ruminal pH dramatically. But when the rate of acid production is faster than the rate of absorption, the VFA accumulate within the rumen (Owens *et al.*, 1998). During SARA, ruminal pH can drop below 5.5 with very low concentrations of lactate in the rumen (Plaizier 2004; Plaizier *et al.*, 2001). Lactic acid may increase during adaptation to dietary changes (Owen, 1998), but it is generally an insignificant intermediary ruminal metabolite and may not have a great effect on ruminal pH during SARA (Allen, 1997). Owens *et al.* (1998) indicated that VFA are responsible for the pH depression between 5.0 and 6.0, whereas lactic acid production rarely occurs above a pH 5.0. Thus, total rumen acid load (mainly VFA), rather than lactate alone, is likely responsible for ruminal pH depression in SARA in the current study. The amount of carbohydrate that is necessary to induce ruminal acidosis varies with composition and fermentability of the non-fiber carbohydrate (NFC) fraction (Allen, 1997), and the content and degree of fineness of the structural carbohydrate (Mertens, 1997; Yang *et al.*, 2001; Zebeli *et al.*, 2006). In the present study, cows fed fine (FS) diets maintained a lower ruminal pH longer

than cows fed coarse (CS) diets after afternoon feeding (Figure 2b). This indicates that increasing level of peNDF_{>1.18} mitigated ruminal pH depression. However, the effect of increasing peNDF_{>1.18} on ameliorating ruminal pH depression was more apparent for cows fed high AV concentrate than those fed low AV concentrate. The lower effect of increased peNDF_{>1.18} on mitigating ruminal pH depression in low AV diets may have been caused by higher buffering capacity of low AV concentrate as opposed to the high AV concentrate. The low AV concentrate was mainly composed of 46.1 % wheat bran, which had high buffering capacity and could sustain a high rumen fluid pH during 24 h incubation (Rustomo *et al.*, 2006a).

Although increasing peNDF is believed could effectively stimulate chewing activity and salivary buffering, the current study showed that ruminal pH was not affected by peNDF_{>1.18} (Table 4). Mertens (1997) recommended that dairy cow diets contain a minimum of 22 % (± 1.0 to 2.0%) peNDF_{>1.18} of ration DM or cows consume 4.4 kg d⁻¹ peNDF_{>1.18} to maintain a daily mean ruminal pH of 6.0 (Mertens, 1997). Zebeli *et al.* (2006), estimated a minimum requirement of 19 % (± 2.0 %) peNDF_{>1.18} of ration DM, or 4.1 kg d⁻¹ (0.6 kg/100 kg of body weight) of peNDF_{>1.18} intake for the dairy cows fed CF to maintain mean daily ruminal pH 6.0. The peNDF_{>1.18} (> 39 %DM) and peNDF_{>1.18} intake (> 5 kg DM d⁻¹) of all experimental diets in the present study were greater than the critical value of peNDF_{>1.18} or peNDF_{>1.18} intake. All experimental diets are expected to be adequate in effective fiber, and therefore, the effect of peNDF on ruminal pH was

small and not significant as compared to the effect of AV.

The present study give another prove that increasing $\text{peNDF}_{>1.18}$ over the critical value did not have a significant effect on ruminal pH changes. Other previous studies (Kononoff and Heinrichs (2003a and b), found that increasing dietary $\text{peNDF}_{>1.18}$ above critical value (from 25.7 to 32.4 %DM) did not have significant effect on ruminal pH. The $\text{peNDF}_{1.18}$ values were all above the proposed minimum $\text{peNDF}_{>1.18}$ values to maintain daily mean ruminal pH 6.0 (Mertens, 1997 and Zebeli *et al.*, 2006); i.e. the hypothetical ruminal acid-base equilibrium (Pitt *et al.*, 1996). Also, all diets tested in the present study (Table 3) and in the studies of Kononoff and Heinrichs (2003a and b) had dietary NDF content of 29.1 to 32.6 (%DM), a range of NDF values that are far greater than the minimum dietary NDF recommendation of 25 % (NRC, 2001). In the study of Krause *et al.*, (2002b), who found a significant effect of forage particle size on ruminal pH, the diets had dietary effective NDF values of 13.6 to 14.4 (%DM), and had an average dietary NDF content of 24.0 (%DM), which was below the critical value of $\text{peNDF}_{>1.18}$ and NDF. Evaluation of time distribution using a frequency distribution curve of time at pH 5.0 up to 7.2 (Figure 3), shows that the time distribution curve of HA cows was shifted to a lower pH range, and hence, HA cows spent longer time at sub-optimum ruminal pH than that of LA cows. Additionally, when cows were fed CF of HA concentrate with coarse forage (CS) or higher $\text{peNDF}_{>1.18}$, they spent less time at sub-optimum ruminal pH of 5.8 (290.5 vs. 194.9 min d^{-1} , $P = 0.01$,

data not shown) and longer time at optimum pH of 6.4 (179 vs. 239.3 min d^{-1} , $P = 0.06$, data not shown) as compared to the cows fed LA concentrate with coarse forage or higher $\text{peNDF}_{>1.18}$. These results suggest that increased $\text{peNDF}_{>1.18}$ attenuated ruminal pH drops presented by a shorter time spent at low ruminal pH 5.8 and/or by the longer time spent at high ruminal pH 6.4. However, the effect of increasing FPS on ameliorating ruminal pH depression was more apparent with the consumption of HA concentrate than with LA concentrate. As mentioned earlier, the small effect of increased $\text{peNDF}_{>1.18}$ on attenuating ruminal pH drops in LA diets observed in the present study may have resulted from a higher intrinsic buffering capacity of LA concentrate as reflected by lower acid-load from LA concentrate compared to the HA concentrate (190.65 vs. 211.75 mg Ca/kg DM; $P = 0.008$, data not shown).

All experimental CF diets did not affect dry matter intake (DMI). The significant decrease in DMI caused by increasing fermentability of feeds found in the study of Krause *et al.*, (2002a) was likely because of the more severe ruminal pH depression demonstrated by the longer time spent below pH 5.8 (10.8 h d^{-1}) (Krause *et al.*, 2002b). Thus, the result of the present study also give another attention to the importance of the relationship between the extent of ruminal pH depression below pH 5.8 and the DMI depression. There may be a critical time of ruminal pH depression below pH 5.8, above which the depression would affect DMI depression. The effect of time and ruminal pH depression on DMI depression warrant further study.

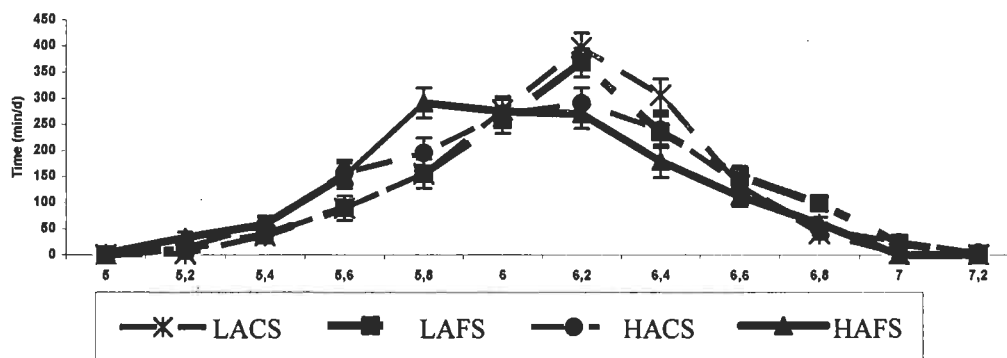


Figure 3. Time spent at ruminal pH 5.0 to 7.2 for the dietary treatments (HACS = high acidogenic value concentrate, coarse forage; HAFS = high acidogenic value concentrate, fine forage; LACS = low acidogenic value concentrate, coarse forage; LAFS = low acidogenic value concentrate, fine forage).

Conclusion

Rumen acidosis depression was more affected by the direct effect of increased acid load (AV) derived from feed fermentation within the rumen, rather than the indirect effect of rumen buffering due to consumption of effective fiber (peNDF_{>1.18}). The small and non significant effect of peNDF_{>1.18} of CF on rumen acidosis was likely due to the high dietary peNDF_{>1.18} or high dietary NDF of the experimental complete feed diets above that of the critical value recommended to affect ruminal pH depression. Using dietary AV approach is likely more useful to predict ruminal pH changes than using the peNDF or NDF approach. Therefore, using the AV and peNDF_{>1.18} approaches would give a better diet formulation to mitigate rumen acidosis depression in dairy cows, rather than using the peNDF_{>1.18} approach alone.

References

- Allen, M. S., 1997. Relationship between fermentation acid production in the rumen and the requirement for physically effective fiber. *Journal of Dairy Science* 80: 1447-1462.
- Allen, M.S., 2000. Effect of diet on short-term regulation of feed intake by lactating dairy cattle. *Journal of Dairy Science* 83: 1598-162.
- AlZahal, O., B. Rustomo, T. F. Duffield, and B. W. McBride. 2006. A cordless system for continuous recording of ruminal pH in dairy cows. *Journal of Dairy Science*, 88 (Suppl. 1): 193 (Abstr. T228).
- Armentano L. and M. Pereira. 1997. Measuring the effectiveness of fibre by animal response trial. *Journal of Dairy Science*, 80:1416-1425.
- ASAE. 2001, S424. *Method of determining and expressing particle size of chopped forage materials by sieving*. Standards Am. Soc. Agric. Eng., St. Joseph, MI.
- Association of Official Analytical Chemists. 1990. *Official method of analysis*. 15th ed. AOAC, Washington, DC.
- Beauchemin, K. A. and W. Z. Yang, 2005. Effects of physically effective fiber on intake, chewing activity, and ruminal acidosis for dairy cows fed diets based on corn silage. *Journal of Dairy Science* 88: 2117-2129.
- Buckmaster, D.M., 2000. *Particle size in dairy cows*. In Recent advances in animal nutrition. P. C. Garnsworthy and J. Wisemna, ed. Pages 109-128 Nottingham University Press, Nottingham, UK.
- Calberry, J. M., J.C. Plaizier, M.S. Einarson and B.W. McBride 2003. Effects of replacing chopped alfalfa hay with alfalfa silage in a total mixed ration on production and rumen conditions of lactating dairy cows. *Journal of Dairy Science* 86: 3611-3619.
- Cooper, R. and T. Klopfenstein, 1996. *Effect of Rumensin in feed intake variation on ruminal pH*. Scientific Update on Rumensin/Tylan/Mycotil for the Professional Feedlot Consultant. Elanco Animal Health, Indianapolis, IN.
- Cooper, S. B. D., Kyriazakis, I. and J. V. Nolan, 1995. Diet selection in sheep: the role of the rumen environment in the selection of a diet from two feeds that differ in their energy density. *British Journal of Nutrition* 74: 39-54.
- Cumby, J. L., Plaizier, J. C., Kyriazakis, I. and B. W. McBride. 2001. Effect of subacute ruminal acidosis on the preference of cows for pellets containing sodium bicarbonate. *Canadian Journal of Animal Science* 81: 149-152.
- Dewhurst, R. J., Wadhwa, D., Borgida, L. P. and W. J. Fisher. 2001. Rumen acid production from dairy feeds. 1. Effects on feed intake and milk production of dairy cows offered grass or corn silages. *Journal of Dairy Science* 84: 2721-2729.
- Garret, E.F., M.N. Pereira, K.V. Nordlund, L.E. Armentano, W.J. Goodger, and G.R. Oetzel. 1999. Diagnostic methods for detection of subacute ruminal acidosis in dairy cows. *Journal of Dairy Science* 82: 1170-1178.
- Hall, M. B. 2000. Starch gelatinization and hydrolysis method. Neutral detergent soluble carbohydrates, Nutritional Relevance and Analysis – A Laboratory manual (p.29 –38). Dept. of Animal Science, Univ. of Florida, Gainesville 3261-0910.
- Heinrichs, J. A. and Kononoff, P. J., 2002. *Evaluating particle size of forages and TMRs using the New Penn State Particle Size Separator*. Penn State, University Park, PA.
- Keunen, J. E., Plaizier, J. C., Kyriazakis, I., Duffield, T. F., Widowski, T. M., Lindinger, M. I. and B. W. McBride. 2002. Effect of sub-acute ruminal acidosis model on the diet selection of dairy cows. *Journal of Dairy Science* 85: 3304-3313.
- Kleen, J. L., Hooijer, G. A., Rehage, J. and J. P. Noodhuizen. 2003. Subacute ruminal acidosis (SARA): A Review, *Journal of Veterinary Medicine A Physiology Pathology Clinic Medical* 50: 406-414

- Kononoff, P. J. and A. J. Heinrichs. 2003a. The effects of reducing alfalfa haylage particle size on cows in early lactation. *Journal of Dairy Science* 86: 1445-1457.
- Kononoff, P. J. and A. J. Heinrichs. 2003b. The effects of corn silage particle size on cows in early lactation. *Journal of Dairy Science* 86: 2438-2451.
- Kononoff, P. J., Heinrichs, A. J. and D. R. Buckmaster. 2003a. Modification of Penn state forage and total mixed ration particle separator and the effects of moisture content on its measurements. *Journal of Dairy Science* 86: 1858-1863.
- Kononoff, P. J., Heinrichs, A.J. and H. A. Lehman. 2003b. The effect of corn silage particle size on eating behavior, chewing activities, and rumen fermentation in lactating dairy cows. *Journal of Dairy Science* 86: 3343-3353.
- Krause, K. M. and D. K. Combs. 2003. Effects of particle size, forage, and grain fermentability on performance and ruminal pH in mid lactation Cows. *Journal of Dairy Science* 86: 1382-1397.
- Krause, K. M., Combs, D. K. and K. A. Beauchemin. 2002a. Effects of particle size and grain fermentability in mid lactation cows. I. Milk Production and diet digestibility. *Journal of Dairy Science* 85: 1936-1946.
- Krause, K. M., Combs, D. K. and K. A. Beauchemin. 2002b. Effects of particle size and grain fermentability in mid lactation cows. II. Ruminal pH and chewing activity. *Journal of Dairy Science* 85: 1947-1957.
- Krause, K.M., Combs, D.K. and K.A. Beauchemin, 2003. Effect of increasing levels of refined cornstarch in the diet of lactating dairy cows on performance and ruminal pH. *Journal of Dairy Science* 86: 1341-1353.
- Mertens, D. R., 1997. Creating a system for meeting the fiber requirements of dairy cows. *Journal of Dairy Science* 80: 1463-1481.
- Nocek, J.E., 1997. Bovine Acidosis: Implications on Laminitis. *Journal of Dairy Science*, 80: 1005- 1028.
- Owens, F. N., D. S. Secrist, W.J. Hill, and D.R. Gill, 1998. Acidosis in cattle: A Review. *Journal of Animal Science* 76: 275-286.
- Oetzel, G.R. 2000. Clinical aspects of ruminal acidosis in dairy cattle. *Proceeding of American Association Bovine Practices* 33: 46-53.
- Pitt, R. E., Van Kessel, J. S., Fox, D. G., Pell, A. N., Barry, M. C. and P. J. Van Soest. 1996. Prediction of ruminal volatile fatty acids and pH within the net carbohydrate and protein system. *Journal of Animal Science* 74: 226-24.
- Plaizier, J. C. 2004. Replacing chopped alfalfa hay with alfalfa silage in barley grain and alfalfa based total mixed rations for lactating cows. *Journal of Dairy Science* 87: 2495-2505.
- Plaizier, J. C., Martin, A., Duffield, T. F., Bagg, R., Dick, P. and B. W. McBride. 2001. Effect of subacute ruminal acidosis on in situ digestion of mixed hay in lactating dairy cows. *Canadian Journal of Animal Science* 81: 421-423.
- Rustomo, B., J.P. Cant, M.Z. Fan, T.F. Duffield, N.E. Odongo and B.W. McBride, 2006a. Acidogenic value of feeds I. The relationship between the acidogenic value of feeds and in vitro ruminal pH changes. *Canadian Journal of Animal Science* 86: 109-117.
- Rustomo, B., O. AlZahal, J.P. Cant, M.Z. Fan, T.F. Duffield, N.E. Odongo, and B.W. McBride, 2006b. Acidogenic value of feeds II. Effects of rumen acid-load from feeds on dry matter intake, ruminal pH, fiber degradability and milk production in the lactating dairy cow. *Canadian Journal of Animal Science* 86: 119-126.
- SAS Institute, Inc., 2004. *SAS user's guide. Statistics*. Version 9.1. ed. 2004. SAS Institute, Inc., Cary, NC.
- Underwood, W.J., 1992. Rumen lactic acidosis. Part. Epidemiology and pathology. *Compendium of Continued Education Practice Veterinary* 14: 1127-1133.
- Woodford, S.T., N.A. Jorgensen and G.P. Barrington, 1986. Impact of dietary fiber and physical form on performance of lactating dairy cows in early lactation. *Journal of Dairy Science* 68: 1035-1047.
- Yang, W. Z., K.A. Beauchemin and L.M. Rode, 2001. Effects of grain processing, forage to concentrate ratio, and forage particle size on rumen pH and digestion by dairy cows. *Journal of Dairy Science* 84: 2203-2216.
- Zebeli, Q., M. Tajaf, H. Steingass, B. Metzler, and W. Drochner, 2006. Effects of physically effective fiber on digestive process and milk fat content in early lactating dairy cows fed total mixed rations. *Journal of Dairy Science* 89: 651-66.