Effect of Total Mixed Ration Particle Size on Rumen pH, Chewing Activity and Performance in Dairy Cows

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ABSTRACT : Two experiments were conducted to determine effects of particle size in total mixed ration (TMR) on performance of lactating cows. Three rumen cannulated Holstein cows were used in a 3×3 Latin square design for the metabolic experiment. The particle size of the diets was determined using the Penn State Particle Size Separator (PSPSS) and weighing the proportion of sample remaining on the top screen (19 mm diameter). The 3 treatments were short, medium or long diets (4.9, 24.2 and 27.8% of sample remaining on the top screen of the PSPSS, respectively). Nine farms in the Edmonton area were surveyed and the farms were placed into groups based on the particle size of the ration fed. The groups were short ≤6%, medium 7-12% and long ≥13% of sample weight remaining on the top screen of the PSPSS. Dry matter intake was greater (p=0.07) for the medium diet than the long diet in the metabolic study and resulted in a higher (p=0.07) efficiency of milk production. On the commercial farms, a significantly (p=0.002) lower milk fat percentage was observed for the long diet compared to the short diet. The results of these studies confirm that forage particle size influences milk composition and milk fat was negatively correlated to TMR particle size. ***(Asian-Aust. J. Anim. Sci. 2003. Vol 16, No. 12 : 1755-1762)***

Key Words : Lactation Performance, Forage Particle Size, Rumen Environment

INTRODUCTION

Maintaining a profitable, productive herd is an important goal of dairy producers throughout the world. Many factors including feed quality, milking management, and genetics affect a producer's ability to attain high production levels in their herd (Jordan, 1993). Evaluating feed quality, including particle size, ration uniformity and adequate effective fibre is especially important to producers in Western Canada because the majority of the feed used is produced on farm. Adequate effective fibre in the ration is very important to maintain good rumen health. Ruminal pH is a useful reference for determining the fibre requirements of high producing dairy cows (Allen, 1997). Consequently, feeding insufficient fibre in a lactation ration will alter rumen fermentation, leading to a decrease in ruminal pH, cause mild to severe acidosis, decrease appetite, reduce ruminal motility and inhibit microbial growth. This can affect digestive efficiency, intake and metabolism, milk fat production, and the long-term health of the animal, therefore, impacting economic productivity (Mertens, 1997).

Allen (1997) found that ruminal pH was positively correlated to particle length; as particle size decreases, ruminal pH decreases. Fibre exerts its influence on rumen pH by increasing saliva flow through its effect on chewing and diluting the more fermentable feed components in the rumen (Allen, 1997). Saliva itself is important because it buffers the acids produced in the rumen during digestion. Time spent chewing and the number of chews during eating and rumination are the primary factors that determine the rate of saliva secretion (Okine et al., 1994). Salivary flow is also influenced by diet dry matter, feed intake and particle length (Ruyet et al., 1992).

The objective of this study was to test the hypothesis that the total mixed ration (TMR) particle size may affect rumen pH, feed intake, and performance of lactating cows under controlled experimental conditions. The other objective of this study was to investigate the effect of the TMR particle size on the performance of dairy cows on commercial dairy farms

MATERIALS AND METHODS

Controlled metabolic study

Cows and diets : The animals were cared for according to the guidelines of the Canadian Council on Animal Care. Three multiparous Holstein cows in late-lactation [202, 264, and 318 days in milk (DIM) at the beginning of the study] fitted with ruminal canulas (10 cm i.d., Bar-Diamond Inc., Parma, ID, USA) were tethered in stalls and had free access to water. A 3×3 Latin square design experiment with 3 diets and 2 weeks in each period (one-week adaptation period, one-week measurement period) was utilized. Diets were formulated based on 55% concentrate, 20% alfalfa hay and 25% barley silage on dry matter (DM) basis. The

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Table 1. Ingredient composition of concentrate mixure used in the metabolic study

Ingredient	%, DM basis
Rolled barley	47.95
Rolled corn	13.88
Protein supplement[z]	26.97
Tallow	3.93
Megalac	0.99
Molasses	0.97
Vitamin premix[y]	1.51
Mineral premix[x]	3.80

[x]103 g kg^{-1} Ca, 43 g kg^{-1} P, 89 g kg^{-1} Mg, 102 g kg^{-1} Na, 52 g kg^{-1} Cl, 7 mg kg^{-1} Co, 355 mg kg^{-1} Cu, 654 mg kg^{-1} Fe, 600 mg kg^{-1} Mn, 3.5 mg kg^{-1} Se, 710 mg kg^{-1} Zn. [y]960 KIU kg^{-1} vitamin A, 300 KIU kg^{-1} vitamin D_3, 4,000 IU kg^{-1} vitamin E. [z]145 g kg^{-1} fishmeal, 161 g kg^{-1} corn gluten meal, 145 g kg^{-1} soybean meal, 456 g kg^{-1} canola meal, 93 g kg^{-1} distiller dried grain.

Table 2. Penn State Particle Size Separator measurements of the total mixed ration in the metabolic study

	% of total sample remaining on each pan					
	SP[z]	SD	MP[z]	SD	LP[z]	SD
Top screen	4.9	0.71	24.2	2.72	27.8	11.22
Middle screen	31.2	1.75	26.7	2.83	24.2	5.42
Bottom pan	63.9	1.99	49.1	2.55	48.0	6.30
Total	100		100		100	

[z]Particle size of TMR measured as a % on top pan of Penn State Particle Size Separator (SP=4.9%, MP=24.2%, LP=27.8%).

concentrate portion of the diet (Table 1) was the standard University of Alberta Dairy Research and Technology Centre's (DRTC) grain formulated for mid- to late-lactation animals (post peak production). The TMR contained 19.5% crude protein (CP), 37.0% neutral detergent fibre (NDF), 21.0% acid detergent fibre (ADF), 1.08% Ca, and 0.55% P. The diets were isometric varying only in particle size of the alfalfa hay. The particle size measurement was determined by utilizing the Penn State Particle Size Separator (PSPSS) with the technique outlined by Heinrichs (1996). A 200 g TMR grab sample was placed on the top screen. On a flat surface, the screens were stacked together and shook in one direction five times. The screens were then rotated a one-quarter turn and shook another five times for a total of 8 sets or 40 shakes. The material in each of the two screens and the bottom pan were then weighed and a percentage was calculated.

The medium length particle size (MP) was the standard particle size fed at the DRTC with an average of 24.2% remaining on the top screen. The long length particle size (LP) had an average of 27.8% remaining on the top screen and the short length particle size (SP) had 4.9% remaining on the top screen. Table 2 shows the values of the middle screen and the bottom pan.

Diets were mixed in American Calan Inc. Data Rangers, capacity of 40-45 cu ft. for 3 minutes or a total of 39 revolutions. Cows were fed the TMR (10% in excess of

Table 3. Chemical composition of total mixed ration components used in the metabolic study

	Alfalfa hay	Barley silage	Concentrate
Dry matter (%)	87.80	32.54	87.98
	------------------	---% of DM---	------------------
Organic matter	82.55	90.47	92.62
Crude protein	17.80	13.34	23.94
Neutral detergent fiber	47.97	62.28	21.56
Acid detergent fiber	39.31	39.49	7.55
Calcium	0.20	0.31	0.78
Phosphorus	0.20	0.31	0.78

appetite) once daily at 1,000 h and orts were removed and weighed prior to 1,000 h the following day. Feed offered and feed refusal were recorded daily and the mean dry matter intake (DMI) for the last week of each period was used to determine treatment effect. The TMR was sampled once per period (in the second week of each period), whereas, the composition of forage and grain mixes was determined on the routine monthly samples collected by the DRTC staff. Feed samples were analyzed by wet chemical analysis (Table 3) by Minnesota Valley Testing Labs. Inc. (PO Box 249, New Ulm, MN, USA 56073-0249).

Milk production : Milk yield was recorded daily for the duration of the study. Milk samples were taken from two consecutive milkings on Monday (pm milking) and Tuesday (am milking) of each week and analyzed for protein, fat, and lactose. Analysis was done by the Central Milk Testing Lab at the Western Canadian Dairy Herd Improvement Services (14904-121A Ave., Edmonton, AB, T5V 1A3). The means for milk yield, milk composition, and milk component yield for the last week of each period were used to determine treatment effects. Efficiency of production was calculated by taking the average daily milk yield of the second week of each trial and dividing it by the average daily DMI for the corresponding week.

pH measurements : Rumen, urinary, and fecal samples were collected 4 h post-feeding on day 14 of each replicate and analyzed to determine pH. The pH was measured by glass electrode (Model 5 pH meter, Corning Scientific Instruments, Acton, MA, USA) immediately after sample collection. Rumen samples were collected through rumen cannula by using a stainless steel strainer attached to a plastic tube that was inserted into the rumen. The liquid was extracted by applying a vacuum to the end of the tube with a syringe. Fecal samples were collected by means of grab sample (1 kg). The pH was determined by diluting the sample in distilled water in a 1 ml:1 mg ratio as described by Romond et al. (1998) and measuring with a pH meter. Urine was collected (100 ml) by means of stimulation and the pH was measured with a pH meter.

Blood samples were collected prior to the 1,000 h feeding and two hours post feeding and sent for pH analysis to the Surgical Medical Research Institution (SMRI) at the University of Alberta.

Table 4. Characteristics of farms surveyed in the Edmonton area

Number of animals	Lactation number^{z}	DIM^{z}	Milk^{z}, kg day^{-1}	Milk composition^{z,y}, %		pH		PS^{x}	Forage: grain	% of DM	
				Fat	Protein	Fecal	Urine			NDF	ADF
20	3.2	167.3	35.0	3.6	3.2	6.3	8.2	17.0	55.0	41.6	23.5
18	2.1	166.8	35.5	3.5	3.3	6.7	8.3	7.0	55.0	38.4	20.2
6	2.3	161.3	37.3	3.7	3.1	6.3	8.3	8.0	45.0	40.5	20.7
22	2.1	128.8	38.8	3.6	3.1	6.5	8.1	4.0	50.0	34.2	17.6
14	1.8	176.5	40.6	2.9	3.0	6.3	8.1	17.0	54.0	32.2	15.6
20	2.2	153.9	31.2	3.1	3.0	6.4	8.2	15.2	54.0	37.1	18.5
15	1.5	166.8	31.5	3.7	3.0	6.4	8.0	3.0	55.0	35.3	14.9
6	3.3	125.2	36.6	3.2	3.0	6.2	8.2	12.0	41.0	33.9	16.0
13	2.8	224.8	31.9	3.6	3.0	6.6	8.4	18.0	50.0	39.2	23.6

^{x} Percent total weight of TMR grab sample remaining on top screen of the Pen State Particle Size Separator. ^{y} Days in milk.
^{z} Supplied by Western Canadian Dairy Herd Improvement Services.

Chewing

Chewing activities of the three cows were measured over a 48 h period beginning on day 12 of each period using a device described previously by Okine et al. (1994). A micro-switch was attached to a cord under the cows' jaw and linked to a computerized data acquisition system. These measurements did not interfere with the spontaneous eating, ruminating, and resting behavior of the cows. The chewing recorders were put on the cows on day 12 of each trial and only removed during milking time or if the cow inadvertently caused a disconnection (in which case it was quickly reconnected). After 48 h of data collection, the number of chews in this 48 h period including eating and ruminating chews, was averaged to determine the number of chews per minute.

Statistical analyses

Data were analyzed as a 3×3 Latin square design using the general linear models (GLM) procedure of SAS (1996). Contrasts were also utilized to make specific treatment comparisons. Results were considered significant at $p<0.05$, whereas, a trend was considered to exist if $0.05\leq p\leq0.10$.

Farm total mixed ration survey

The objective of this survey was to evaluate the rations and resulting milk yield and composition as well as fecal and urine pH of high producing cows. The forage to concentrate ratio and the ration particle size was determined on each farm.

Nine farms in the Edmonton area feeding a barley silage, alfalfa hay and barley grain based TMR volunteered for the complete randomized design of this study. Cows were chosen randomly based on one of three lactation groups; post-peak (50-100 DIM), mid-lactation (100-200 DIM) and just prior to dry-off (>200 DIM). The proportion of cows in each lactation group depended on the number of animals available in each herd that fell into each category. Table 4 shows the characteristics of each farm. Samples of urine and feces were collected and analyzed for pH using the techniques described previously. A grab sample of the TMR being fed was also collected and particle size was evaluated using the PSPSS. The farms were then categorized on the basis of particle size of the TMR (groupings based on the percentage of the grab sample remaining on the top screen of the PSPSS). The groups were as follows: the SP group was less than or equal than to 6%, the MP group was between 7 and 12%, and the LP group was greater than or equal to 13% of the TMR sample remaining on the top screen of the PSPSS. Milk production data was collected from the Western Canadian Dairy Heard Improvement Service's July recorded data.

Statistical analyses

Data were analyzed using the GLM procedure of SAS (1996). The model included lactation number (1, 2 and 3, and >3), days in milk (DIM; 50-100, 100-200, and >200 DIM), TMR particle size, lactation number×DIM, and lactation number×TMR particle size. Least square means were compared among lactation number, DIM, and TMR particle size categories. The relationship between milk fat and protein concentrations and milk fat yield with fecal pH, urine pH, TMR particle size, and dietary ADF and NDF were determined by stepwise regression analysis of SAS (1996). Results were considered significant at $p<0.05$, whereas a trend was considered to exist if $0.05\leq p\leq0.10$.

RESULTS

Controlled metabolic study

There was a trend ($p=0.07$) for higher DMI when cows were fed MP diet compared to cows fed the LP diet, but no differences were observed between other dietary treatments (Table 5). No significant differences ($p>0.1$) were observed for milk yield, milk fat and milk lactose percentages, and milk component yield. However, milk protein percentage was significantly ($p=0.02$) higher for cows fed the SP diet compared to cows fed the LP diet. There was a trend ($p=0.06$) for a higher milk protein content for cows fed the SP diet compared to cows fed the MP diet (Table 5). Milk fat:protein ratio was not affected by dietary treatment. Feed

Table 5. Influence of particle size of the total mixed ration on dry matter intake, milk yield and composition, and chewing activity in the metabolic study

	Particle size[z]			SEM[x]	Contrast (p)[y]		
	SP	MP	LP		SP vs. MP	SP vs. LP	MP vs. LP
DMI, kg day^{-1}	24.1	24.8	22.7	0.42	0.35	0.14	0.07
Milk yield, kg day^{-1}	27.4	29.7	29.8	0.93	0.23	0.21	0.95
Milk fat, %	3.49	3.41	3.56	0.11	0.60	0.69	0.37
Milk fat yield, kg day^{-1}	0.93	1.01	1.04	0.03	0.23	0.14	0.59
Milk protein, %	3.18	3.09	3.06	0.02	0.06	0.02	0.25
Milk protein yield, kg day^{-1}	0.86	0.92	0.91	0.03	0.31	0.38	0.84
Milk fat:milk protein	1.11	1.10	1.16	0.06	0.94	0.56	0.52
Milk lactose, %	4.35	4.41	4.45	0.04	0.46	0.20	0.44
Efficiency of production[w]	1.15	1.21	1.32	0.02	0.19	0.03	0.07
Chewing, chews min^{-1}	30.7	33.3	28.7	2.23	0.44	0.57	0.22

[w] Milk yield DMI^{-1} [x] SEM=standard error of the mean. [Y] Significance of effects ($p<0.10$).
[z] Particle size of TMR measured as a % on top pan of Penn State Particle Size Separator (SP=4.9%, MP=24.2%, LP=27.8%).

Table 6. Influence of particle size of the total mixed ration on rumen, blood, fecal, and urine pH in the metabolic study

	Particle size[z]			SEM[x]	Contrast (p)[y]		
	SP	MP	LP		SP vs. MP	SP vs. LP	MP vs. LP
Rumen pH[w]	6.23	6.27	6.23	0.04	0.60	1.00	0.60
Blood pH[v]	7.47	7.45	7.44	0.02	0.48	0.37	0.80
Blood pH[u]	7.41	7.48	7.47	0.02	0.09	0.10	0.79
Fecal pH[w]	6.63	6.63	6.77	0.05	1.00	0.21	0.21
Urine pH[w]	8.13	8.17	8.17	0.08	0.81	0.81	1.00

[u] pH measured 2 h post-feeding. [v] pH measured immediately prior to feeding. [w] pH measured 4 h post-feeding. [X] SEM=standard error of the mean.
[Y] Significance of effects ($p<0.10$). [z] Particle size of TMR measured as a % on top pan of Penn State Particle Size Separator (SP=4.9%, MP=24.2%, LP=27.8%).

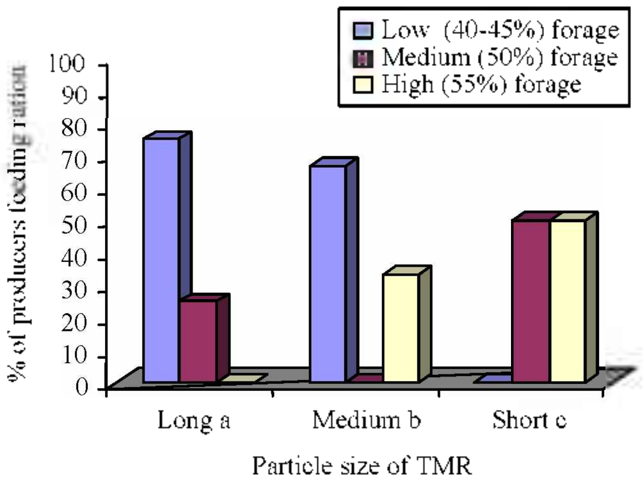

Figure 1. Feeding trends of producers surveyed in the Edmonton area (particle size of the TMR measured as a % of total sample on top pan of the Penn State Particle Size Separator, a; ≥13%, b; 7-12%, c; ≤6%).

particle length also influenced the efficiency of milk production. Cows fed the LP diet produced milk 9% more efficiently (p=0.07) compared to cows fed the MP diet and 12% more efficiently (p=0.03) than those fed the SP diet (Table 5). The total amount of chews (ruminating and eating) appeared to be unaffected (p>0.10) by particle length of the TMR (Table 5). The effect of particle size on rumen, fecal, and urine pH was not significant (p>0.1, Table 6) at 4 hours post-feeding. Treatment did not influence blood pH (Table 6).

Farm total mixed ration survey

The data collected from the farms surveyed was analyzed based on the particle size of the TMR, as well as the stage of lactation and parity. Of the producers feeding the LP TMR, 75% fed a low forage diet (40-45%) and the other 25% of the producers fed medium forage diets (50%, Figure 1). Fifty percent of the producers feeding a SP TMR fed the medium forage level and the other 50% fed a high forage level (55%). The majority of producers (67.7%) feeding a medium particle size TMR used a low forage ration while the remaining 33.3% of producers fed a high forage ration (Figure 1).

The particle size of the diet did not significantly affect milk yield (Table 7). However, cows fed the SP diet had higher milk fat percentage (p<0.05) compared to cows fed the LP diet (Table 7) and milk fat percentage was intermediate for the animals on the MP diet. The farms using a short or long particle length had significantly less milk protein content (3.06 and 3.08%, respectively) than the farms fed MP diet (3.18%, Table 7). Milk yield and milk composition of early-, mid-, and late-lactation cows were different, as expected. The early-lactation animals produced the highest milk yield (p <0.05), mid-lactation animals were intermediate, and late-lactation animals had the lowest yield.

Table 7. Influence of particle size of the total mixed ration, stage of lactation, and parity on milk yield and composition and fecal and urine pH in farms surveyed

	Particle size[z]			SEM[y]	Stage of lactation			SEM	Parity			SEM
	SP	MP	LP		Early	Mid	Late		1	2 and 3	>3	
Yield, kg d^{-1}												
Milk	36.7	36.2	35.9	1.3	40.5[a]	37.7[b]	30.5[c]	1.2	32.2[b]	37.8[a]	38.7[a]	1.2
Milk fat	1.34[a]	1.21[b]	1.15[b]	0.05	1.38[a]	1.21[b]	1.11[b]	0.05	1.07[b]	1.27[a]	1.36[a]	0.05
Milk protein	1.12	1.12	1.10	0.04	1.19[a]	1.15[a]	1.00[b]	0.04	1.01[b]	1.15[a]	1.18[a]	0.04
Milk composition, %												
Fat	3.67[a]	3.43[ab]	3.24[b]	0.10	3.47[a]	3.21[b]	3.67[a]	0.11	3.37	3.42	3.54	0.08
Protein	3.08[b]	3.18[a]	3.06[b]	0.03	2.95[c]	3.06[b]	3.31[a]	0.04	3.14	3.09	3.09	0.04
Fat:protein ratio	1.19[a]	1.08[ab]	1.06[b]	0.03	1.18[a]	1.05[b]	1.11[ab]	0.03	1.08	1.12	1.14	0.03
Fecal pH	6.49[ab]	6.52[a]	6.40[b]	0.04	6.49	6.46	6.46	0.04	6.50[a]	6.40[b]	6.50[a]	0.04
Urine pH	8.08[b]	8.11[ab]	8.21[a]	0.05	8.07[b]	8.06[b]	8.27[a]	0.05	8.01[b]	8.20[a]	8.19[a]	0.05

[a, b, c] Means in a row within category with different superscripts differ ($p<0.05$). [y] SEM=standard error of the mean.

[z] Particle size of TMR measured as a % on top pan of Penn State Particle Size Separator (SP≤6.0%, MP=7.0-12.0%, LP≥13.0%).

Animals with parity of ≥2 produced higher milk yields compared to the first lactating animals. Milk composition was not affected by parity, but milk component yield reflected the milk production. No interactions were found between the TMR particle size and DIM or TMR particle size and parity for any parameters measured, other than a TMR particle size by DIM interaction (p=0.002) was observed for milk protein concentrations (data is not presented).

Cows fed the MP diet had the highest fecal pH, cows fed the LP diet had the lowest fecal pH, and fecal pH was intermediate for cows fed the SP diet (Table 7). Urinary pH was also different between treatments, cows fed the SP diet had the lowest pH, cows fed the LP diet had the highest pH, and cows fed the MP diet were intermediate (Table 7). Urine pH was higher for animals in late-lactation compared with animals in early- and mid-lactation, possibly this reflected the higher forage intake of animals in late-lactation. The urine pH was lower for animals with parity of one compared to animals with parity ≥2, although these changes were small.

Stepwise regression analysis revealed that the correlation between milk fat concentrations or milk fat yield with TMR particle size, ADF and NDF content of the ration, and fecal and urine pH were only significant for the ADF content of the ration and TMR particle size as follow:

Y=2.57 (±0.67)+0.088 (±0.022) ADF-0.376 (±0.079) TMR particle size, p=0.0001, R^2=0.2; where Y=milk fat concentration, %

Y=1.05 (±0.19)+0.027 (±0.011) ADF-0.17 (±0.04) TMR particle size, p=0.0003, R^2=0.15; where Y=milk fat yield, kg d^{-1}

Only 9% of the variation in milk protein concentration was associated with the ADF content of the ration:

Y=2.66 (±0.15)+0.023 (±0.008) ADF, p=0.003, R^2=0.09; where Y=milk protein, %

No correlation was observed between milk composition and urine or fecal pH.

The farms in the survey were asked to complete a questionnaire on nutrition, health and production data for their herd. Two farms stated they had problems with laminitis in approximately 8% and 15-20% of their herd per year. These two farms were in the short particle size category (≤6% of total sample weight remaining on top screen of the PSPSS), even though they were feeding a medium (50%) and high (55%) forage diet, respectively.

DISCUSSION

Generally, recommendations for optimum rumen health and maximum milk fat percentage and milk yield suggest feeding no more than 55% concentrate in a TMR. The forage:concentrate ratio of the farms surveyed were slightly beyond these recommendations ranging from 59% concentrate to 45% concentrate, with a mean of 51%. Heinrichs (1996) suggests a particle size of 6-10% or more of total sample weight of the TMR remaining on the top screen of the PSPSS for optimum rumen health and milk production. Only two out of nine of the producers surveyed were below these recommendations, however, they compensated by feeding a medium to high (50 to 55%) forage in their TMR, thereby, still maintaining recommended levels of effective fiber. The reciprocal of this was also noted in the farms surveyed with producers feeding a LP diet (≥13% of total sample weight on the top screen of the PSPSS). They took advantage of the long particle diet and fed a greater amount of concentrate (50% or greater) in their rations. The one producer feeding the greatest proportion of concentrate in our study (59%) utilized a particle size above the recommended level. The levels of concentrate fed may be more important than the particle size of the forage fed.

Forage particle size did not affect milk yield in either the controlled metabolic study (CMS) (Table 5) or the farms surveyed (Table 7). This agrees with the findings of other studies (Kraus et al., 1999; Belyea et al., 1989). Beauchemin and Rode (1993) stated that the effects of forage chop length on milk yield depends upon the proportion of forage in the diet. A diet with a concentrate level greater than 60% will benefit from increasing the forage particle length because of a higher salivary secretion. No diets fed in this trial exceeded 60% concentrate and, therefore, this effect was not observed. Beauchemin (1991) found daily milk production decreased linearly as NDF content increased but theorized this was due to a corresponding decrease in net energy intake and not the particle size of the forage.

Two most common theories have been postulated to explain the cause of milk fat depression. The first one considers the reduction in milk fat yield to be a consequence of the shortage in the supply of lipid precursors for mammary gland synthesis of milk fat. Acetate is a major precursor for milk fat production, therefore, a reduction in acetate supply and a corresponding increase in propionate supply to the mammary gland results in milk fat depression (Grant and Colenbrander, 1990). The second theory attributes the reduction in milk fat to a direct inhibition of one or more steps in the mammary gland synthesis of milk fat (Griinari and Bauman, 2001). Recent studies (Griinari et al., 1998; Kennelly et al., 1999; Khorasani and Kennelly, 2001) demonstrated that the increase in *trans*-$C_{18:1}$ fatty acids in milk fat was associated with milk fat depression in cows fed a low roughage and not in cows fed high forage diets. Others have also shown low forage diets (Beauchemin et al., 1994) and short particle length (Grant and Colenbrander, 1990; Fischer et al., 1994 Ishler and Adams, 1999) decrease milk fat production. The results of farms surveyed (Table 7) conflict with this literature and portray a significant increase in milk fat with the SP and MP diets over the LP diet. The increase in milk fat production with the SP and MP diets could be explained by a possible greater energy intake relative to the LP diet due to increased DMI. As well, the SP and MP diets had a greater proportion of fibre in their diets. However, we were unable to measure DMI at the farm sites and this point cannot be proven. We can speculate at this point that sorting at the bunker especially when long chop silage is fed could have resulted in relatively less effective fiber intake for LP diets.

Our metabolic study showed no significant differences due to particle size for milk fat production (Table 5), which is consistent with Kraus et al. (1999) and Belyea et al. (1989). Grant (1998) stated that low average herd milk fat was a good indicator of conditions such as sub-clinical acidosis. No health problems were observed in either the CMS or the farms surveyed.

Milk protein has become of greater interest recently because of its increased economic value (Grant, 1998). In our CMS (Table 5), we found that the SP diet produced significantly greater milk protein (3.18%) than the LP diet (3.06%). The farms surveyed results (Table 7) showed that animals fed the MP diet produced the greatest milk protein (3.18%) versus animals fed the SP and LP diets (3.06 and 3.08%, respectively). In contrast, Kraus et al. (1999) found that forage particle size had no effect on milk protein production.

Rumen pH is determined by the degree of digestibility and rate of fermentation of the feed consumed. High concentrate rations have a shorter rumination time because they are highly digestible compared to high forage rations (Kaufmann, 1976). The shorter rumination time results in less saliva production, increased acid production and lower pH. The same can be said for forages with a fine particle size; they are highly digestible, quickly fermented and result in a lower rumen pH (Grant and Colenbrander 1990, Allen 1997). The desirable average daily rumen pH is approximately 6.0 to 6.3 consisting of small within day ranges (Allen and Beede, 1996). The mean ruminal pH from the CMS (Table 6) fall into this range (6.3). No significant difference ($p>0.1$) was observed between the different particle size diets and their effect on rumen pH 4 h or 8 h post-feeding in this study (data not shown). There are several possible explanations for this, including the fact that the diet was 45:55 forage to concentrate ratio creating a stable rumen environment. Had there been a higher level of concentrate in the diet creating an unstable environment, the particle size of the forage would have been more influential on rumen conditions. Another reason for the lack of in rumen pH is that the SP diet may have provided sufficient effective fiber and the threat of creating acidic rumen conditions was never realized. This may also explain the observed higher milk fat with SP diets. Rumen pH values were not available from the farms surveyed as cows were not fistulated.

Wheeler and Noller (1977) stated that fecal pH is a suitable indicator of intestinal pH as they found no significant differences between fecal and small intestinal pH. Low intestinal pH is associated with a higher rate of passage, which can reduce digestibility and absorption of nutrients (Ferreira et al., 1980). Gaylean et al. (1979) found that fecal pH decreased as intake increased and they detected a parallel between fecal and ruminal pH. In the CMS, we did not find any significant differences in fecal pH between diets, which can be expected because the diets were not designed to create extreme rumen conditions. In the farms surveyed (Table 7) fecal pH for cows fed the MP diet was significantly higher than for cows fed the LP diet

(Table 7). This is contrary to the literature examined, however, there is a possibility that with feeding barley silage, some barley grain is passing to the lower gut to be further digested thus causing an impact on fecal pH.

No significance differences in urinary pH were detected in the CMS (Table 6). However, data from the farms surveyed (Table 7) did show that urine pH was significantly lower for animals fed the SP diet (8.05) compared to animals fed the LP diets (8.21) which is contrary to the limited literature available.

Reduction of particle size has been associated with increased DMI (Beauchemin and Rode 1993, Beauchemin et al., 1994). There is a decrease in retention time and, furthermore, reduced microbial fermentation by feeding a shorter particle size diet, which increases voluntary intake to compensate for the reduced digestion of nutrients (Cheeke 1999). However, Belyea et al. (1989) stated that DMI was unaffected by particle size of the diet. In the CMS, there was a trend for higher DMI in cows fed SP and MP diets than cows fed the LP diet. Fischer et al. (1994) added long alfalfa hay to a TMR consisting of 45% forage and they found that it enhanced DMI without an effect on production, thus decreasing the efficiency of production. This conflicts with data from our CMS where we observed a 9 and 12% increased production efficiency for cows fed the LP diets compared to those fed the MP and SP diets respectively. Since we did not measure the body weight or body condition changes and the study was limited to a 2 week experimental period, we cannot explain these inconsistencies.

Time spent eating and ruminating is a function of both dietary and animal factors (Beauchemin, 1991, Njoka-Njiru et al., 2001) although, the dietary factors are the only ones that can be manipulated. Changes in chewing behavior are caused by forage particle size rather than level of intake (Grant, 1998). Beauchemin and Buchanan-Smith (1989) found that cows chew forages of longer particle size more efficiently than shorter particle sizes because each bolus is chewed faster and is subject to more chews although this may depend on whether the animals are grazing or TMR fed (Hasegawa and Hidari, 2001).In our metabolic study, no significance was found between the different particle sizes of the forage and milk yield or milk fat content, which may reflect the high fibre content of the diets. The fibre requirement for lactating dairy cows as recommended by the NRC (1989) only takes into consideration the chemical characteristics of fibre and neglects the physical characteristics. Numerous researchers believe that in order to formulate a balance dairy ration, both chemical and physical characteristics must be considered (Allen, 1997; Mertens, 1997). It is possible that when dairy cows are supplied with adequate dietary fibre, the physical form of the fibre becomes less important.

CONCLUSION

Higher levels of concentrates and low effective fibre due to insufficient particle size in TMR reduce DMI, chewing and salivation creating acidic rumen conditions. The treatment levels of particle size and forage to concentrate ratio of the TMR in our CMS were not extreme enough to elicit these responses from the cows or alternatively, the high fibre content of the diets prevented the depression in rumen pH.

In the commercial farms surveyed, producers were utilizing existing recommendations for forage levels and particle size to maximize the benefits of feeding effective fibre. They were feeding longer forage when the level of forage in the diet was low and using shorter particle size when the level of forage was high. The correlation analysis reveal that the TMR particle size and ADF content may predict the milk composition, although, only up to 20% of the variations in milk composition can be associated with these parameters. However, milk composition was not correlated to the NDF content of the diets or urine and fecal pH.

Further research is required to determine the optimum forage particle length in conjunction with the optimum forage to concentrate ratio to optimize production efficiency and animal health.

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