Milk from Forage as Affected by Carbohydrate Source and Degradability with Alfalfa Silage-Based Diets

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ABSTRACT

Milk from forage (MF) is an estimation of the milk produced solely from forage intake. It is calculated by subtracting milk production theoretically allowed by concentrates from total milk production, assuming that maintenance requirements are covered by the forage portion of the diet. Eight multiparous Holstein cows in early lactation were used in a replicated 4 × 4 Latin square design to evaluate the impact on MF of different sources of carbohydrate with forage that was high in RDP. Diets were alfalfa-based total mixed rations that were formulated to provide similar concentrations of NE_L and CP while differing in rumen degradability of concentrate carbohydrates. Treatments were 1) cracked corn (control), 2) ground corn (GC), 3) GC plus wheat starch (GC+S), and 4) GC plus dried whey permeate (GC+W). The GC and the GC+S treatments increased MF as calculated on a protein basis (14.8 vs. 10.5 kg) and increased average MF production (8.6 vs. 5.5 kg) compared with the control. Protein of forage was used more efficiently with GC and with GC+S, as shown by the lower differences between allowable MF, which estimates the potential for milk production from forage, and MF on a protein basis for these 2 treatments when compared with the control. Compared with the control, DMI increased with GC and GC+S; GC+W yielded the highest DMI. Milk production with GC+W (35.8 kg/d) was lower than with GC and GC+S (37.5 kg/d) but was higher than the control (34.0 kg/d). Milk fat concentration was higher with GC+W and lower with GC+S; GC and the control had intermediate values. Milk urea was higher with the control diet compared with the other 3 treatments. Results emphasize the advantage of using concentrates of higher degradability in the rumen to improve MF and milk production when feeding silage with high rumen-degradable protein.

Key words: milk from forage, rumen carbohydrate degradability, dairy cow, alfalfa silage

INTRODUCTION

Milk from forage (MF) is a theoretical estimate of milk produced from the forage portion of the diet after subtracting milk production theoretically allowed by concentrates from actual milk production, assuming that maintenance requirements are covered by the forage portion of the diet (Charbonneau et al., 2003). High MF has shown economic value to dairy farms (Pellerin et al., 2002). It is widely used in Québec dairy farm management and Québec DHI as a simple management tool to estimate forage use, efficiency of concentrates distribution, and profits. Milk from forage was introduced >25 yr ago (Agri-Gestion Laval, 1978) but was updated recently (Charbonneau et al., 2003) to reflect NRC (2001) requirements. In Quebec in 2000, dairy farm operating profit was on average Can\$15,995 higher for the top 20% compared with the bottom 20% in MF production (Charbonneau et al., 2003). Higher profits were related to reduced production costs, which were mostly feed and health costs. Although production of MF was associated with a reduction in the amount of concentrates in the diet (Pellerin et al., 1999), other factors also needed to be considered for further improvements to MF. Previous studies (Pellerin et al., 1999, 2002) pointed toward the importance of a more complementary combination of concentrates and forages to optimize the production of MF.

Alfalfa silage contains high levels of CP but also a high proportion of RDP (Broderick, 1995). Therefore, complementing a dairy cow diet based on alfalfa silage with concentrates of high carbohydrate degradability in the rumen should optimize the use of RDP for microbial protein synthesis. Feeding nonstructural carbohydrates with increased rumen degradability obtained through mechanical and heat treatments of feed or by selecting highly degradable carbohydrates such as lactose increased ruminal use of NH₃ N (Casper and Schingoethe, 1986, 1989; Broderick et al., 2002). Milk performance varied among studies when feeding carbohydrates with higher ruminal degradability. Most studies (Ekinici and Broderick, 1997; Wilkerson et al., 1997; Dhiman et al., 2002), but not all (Aldrich et al., 1997), have found that carbohydrate sources with high rumen degradability in-

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Table 1. Ingredients of experimental diets (% DM basis)

Ingredient	Treatment ¹			
	Control	GC	GC+S	GC+W
Alfalfa silage	45.0	45.0	45.0	45.0
Cracked corn	46.6	—	—	—
Ground corn	—	46.6	35.0	35.0
Wheat starch ²	—	—	10.6	—
Dried whey permeate ³	—	—	—	10.6
Treated soybean meal ⁴	7.4	7.4	8.4	8.4
Vitamins and minerals ⁵	1.0	1.0	1.0	1.0

¹Control treatment included cracked corn. GC = ground corn, GC+S = ground corn plus wheat starch, and GC+W = ground corn plus dried whey permeate.

²Wheat starch was supplied by Agribrands Purina Canada, Woodstock, Ontario, Canada.

³Dried whey permeate was supplied by Agropur, Granby, Québec, Canada.

⁴Treated soybean meal: Top Soy is a chemically treated soybean meal to reduce protein degradability (Shur-Gain, Brossard, Québec, Canada).

⁵Mineral composition: Ca = 1.52%, P = 5.58%, Na = 20.48%, Cl = 33.18%, Mg = 10.15%, K = 0.01%, S = 0.10%, Cu = 761 mg/kg, Mn = 2,538 mg/kg, Zn = 3,807 mg/kg, Fe = 2,250 mg/kg, Co = 28 mg/kg, I = 76.14 mg/kg, Se = 30.46 mg/kg, vitamin A = 337,500 UI/kg, vitamin D = 112,500 UI/kg, and vitamin E = 5,000 UI/kg.

creased milk production. Dried whey may be an exception. Although it is a good source of lactose, which is mostly degraded in the rumen (King and Schingoethe, 1983), production trials showed no impact on milk performance, but increased milk fat concentration (Schingoethe, 1976; Casper and Schingoethe, 1989).

Therefore, the objective of the present study was to determine the effect of feeding carbohydrates with different rumen degradability on MF in dairy cows fed a diet based on alfalfa silage. The influence of corn grinding as well as substituting corn with wheat starch and dried whey permeate was measured on milk production and composition, MF, rumen parameters, and blood metabolites.

MATERIALS AND METHODS

Cows, Diets, and Experimental Design

Eight multiparous Holstein cows in early lactation [DIM, 94 ± 28 ; parity, 3.3 ± 1.2 ; BW, 614 ± 62 kg; milk yield, 36.2 ± 7.31 kg/d (mean $\pm$ SD)], including 4 cows with rumen fistula, were used in a replicated 4×4 Latin square design with 3-wk periods. Fistulated cows were assigned to the same square. The first 14 d of each period were allowed for adaptation to the diet, and the last 7 d were used for data collection. All cows were fed an alfalfa-silage based diet (45% of DM) with treated soybean meal, plus a concentrate differing in rumen carbohydrate degradability (Table 1). Treatments were 1) cracked corn (control), 2) ground corn (GC), 3) ground

corn plus wheat starch (GC+S), and 4) ground corn plus dried whey permeate (GC+W). Diets were formulated based on NRC (2001) recommendations to provide a similar level of NE_L (1.55 Mcal/kg) and CP (18%). Diets were fed as TMR once daily in the morning to provide 10%orts on an as-fed basis according to the previous day's intake. Before the experiment began, a 2-wk period was set aside for cow adaptation to experimental feeds. Alfalfa silage DM was determined twice weekly in a forced-air oven at 65°C for 3 d. Feed ingredients of TMR were adjusted weekly to ensure a stable proportion on a DM basis throughout the study. Cows were milked twice daily at 0700 and 1700 h. The experimental protocol was approved by the Laval University Animal Care committee, and animals were cared for according to guidelines of the Canadian Council of Animal Care (1993).

Measurements and Sampling

During the last week of each period, BW of cows was recorded on 3 consecutive d, after morning milking to ensure at least 2 similar weights. Feed intake was recorded each day. Total mixed ration was sampled 4 times a week, and orts were sampled the following day. Subsamples were pooled by treatments per period and kept at -20°C for chemical analysis. Milk yield was recorded, and milk was sampled with 2-bromo-2-nitropropan 1,3 diol as preservative for the last 8 consecutive milkings.

On the last day of each period, rumen fluid samples were taken from the fistulated cows at 0, 1, 2, 4, and 6 h postfeeding. The sampling device was a 55-cm long plastic tube (4 cm i.d.) with a 1-mm sieve at the extremity. A 1-kg metal ring was attached to the distal part of the tube to keep the tip in the ventral sac of the rumen. The other extremity was connected to the fistula stopper. Rumenal fluid was sampled with polyvinyl chloride tubing that passed through the plastic tube. The first portion of fluid extracted from each sampling was discarded. Rumenal fluid pH was taken immediately after sampling (Oakton pH 10 Series, Vernon Hills, IL). Samples were cooled on ice until they were centrifuged at $2,400 \times g$ for 20 min at 4°C to remove feed particles. The supernatant was acidified to inhibit fermentation and minimize ammonia volatilization. One aliquot was acidified with 1 N H₃PO₄ (5 parts ruminal fluid:1 part H₃PO₄) and frozen at -20°C until VFA analysis (Boukila et al., 1995). The second aliquot was acidified with 1 N H₂SO₄ (5 parts rumen fluid:1 part H₂SO₄) and frozen at -20°C until NH₃ N analysis (Boukila et al., 1995).

Caudal vein blood samples were collected twice by venipuncture in EDTA tubes on d 20 of each period, once before feeding (0900 h) and once in the afternoon (1500 h). Samples were cooled on ice until plasma was har-

vested after centrifugation at $2,400 \times g$ for 15 min at 4°C . Plasma was kept at -20°C until analysis.

Chemical Analysis

Total mixed rations and orts were freeze-dried. Once dried, they were ground in a Wiley Mill (Arthur H. Thomas Co., Philadelphia, PA) through a 2-mm screen and then in a Cyclotec 1093 Sample Mill (Tecator Inc., Höganäs, Sweden) through a 1-mm screen. Total mixed rations and orts were analyzed for ADF and NDF using the Ankom immersion method (Ankom²⁰⁰ Fiber Analyzer, Fairport, NY) (Ankom Technology, 1999a,b) and for CP following the Kjeldahl procedure [Kjel-Foss Automatic 16210; A/SN, Foss Electric, Hillerød, Denmark] (AOAC, 1990). Ash was analyzed according to a standard procedure (AOAC, 1990).

Dry matter intake was calculated for each cow by subtracting orts from TMR offered on a DM basis. Intake of ADF, NDF, and CP was calculated by subtracting each component quantity in orts from its quantity in TMR.

Milk samples from each individual milking were analyzed by the Program d'analyse des troupeaux laitiers du Québec (Ste-Anne de Bellevue, Québec) for fat, protein, lactose, and MUN concentrations. Fat and protein concentrations were determined using a Foss Milkoscan 4000 (Foss Electric) combined with a Bentley 2000 (Bentley Instruments, Chaska, MN). Lactose and MUN were measured with a Foss Milkoscan 4000 (Foss Electric). Averages were then calculated for each cow at each period.

Thawed rumen fluid was analyzed for VFA and NH_3 N. Samples were centrifuged at $2,000 \times g$ for 10 min at 4°C , after which supernatant was filtered through a $0.45\text{-}\mu\text{m}$ membrane. The supernatant was analyzed by HPLC (Gold system, Beckman Instruments Inc., San Ramon, CA) for VFA concentration (Canale et al., 1984). Rumen fluid NH_3 N was determined according to the procedure of McCullough (1967) using a spectrophotometer (Hewlett Packard 8453, Walbronn, Germany) at 625 nm.

Urea concentrations in plasma were determined using a colorimetric method (Huntington, 1984) with a Technicon analyzer (Technicon Autoanalyzer II, Technicon Instruments Corporation, Tarrytown, NY). Glucose concentrations were determined with colorimetric kits from Boehringer Mannheim (Dorval, QC, Canada). An enzymatic procedure with a kit (#990-75401, Wako Chemicals, Dallas, TX) was used to determine NEFA concentrations, as described by McCutcheon and Bauman (1986).

Calculations of MF

Milk from forage was calculated for each cow as proposed by Charbonneau et al. (2003):

$$\text{MF}_{\text{energy}} (\text{kg}) = \text{ECM} (\text{kg}) - \frac{[\text{NE}_L \text{concentrate} (\text{Mcal}) - \text{NE}_L \text{req BW change} (\text{Mcal})]}{0.75 \text{ Mcal/kg milk}}$$

where $\text{ECM} (4\% \text{ fat}, 3.4\% \text{ CP}, \text{kg}) = \text{milk} (\text{kg}) \times (0.124\% \text{ fat} + 0.073\% \text{ CP} + 0.256)$.

$$\begin{aligned} \text{NE}_L \text{concentrate} (\text{Mcal}) &= \text{DMI} (\text{kg}) \\ &\times \sum_{i=1}^n \text{percentage of DMI of concentrate}_i \\ &\times \text{NE}_L \text{ of concentrate}_i (\text{Mcal/kg}) \end{aligned}$$

where $i = 1, 2, \dots, n$, and n is the number of concentrates.

$$\begin{aligned} \text{NE}_L \text{ req for BW change} (\text{Mcal}) &= \text{BW change} (\text{kg}) \\ &\times \text{NE}_L \text{ req} (\text{Mcal/kg of BW change}) \end{aligned}$$

where $\text{NE}_L (\text{Mcal/kg of BW change}) = 5.34 \text{ Mcal/kg of BW gain} = -4.68 \text{ Mcal/kg of BW lost}$.

Coefficients in equations originated or were adapted from the NRC (2001). Some adjustments were made to make MF equations easier to use, as the primary objective of MF is for farm management purposes. The 0.75 Mcal/kg of milk was obtained from equation 2-16 of NRC (2001, p 19) used to calculate NE_L needs per kilogram of milk for milk containing 4% fat and 3.4% protein. With this coefficient, it is possible to evaluate the quantity of milk theoretically produced from the concentrates and subtract it from ECM. The ECM equation was the milk production multiplied by an adjustment factor calculated using equation 2-16 of NRC (2001) for NE_L needs per kilogram of milk divided by 0.75 Mcal/kg . The adjustment factors corrected milk with different composition to a comparable energy level. The values of NE_L for concentrates were calculated using a 74% diet TDN_{1x} with an intake above maintenance at $3 \times$ maintenance. The NE_L requirement for BW change values was the relative NE_L needed or provided to gain or lose 1 kg of live weight for a cow with a BCS of 3 (NRC, 2001).

$$\begin{aligned} \text{MF}_{\text{protein}} (\text{kg}) &= \text{PCM} (\text{kg}) \\ &- \frac{[\text{CP concentrate} (\text{kg}) - \text{CP req for BW change} (\text{kg})]}{0.088 \text{ kg of CP/kg of milk}} \end{aligned}$$

where $\text{PCM} (\text{protein-corrected milk}; 3.4\% \text{ CP}, \text{kg}) = \text{milk} (\text{kg}) \times 0.294\% \text{ CP}$.

$$\begin{aligned} \text{CP concentrate} (\text{kg}) &= \\ \text{DMI} (\text{kg}) \times \sum_{i=1}^n [\% \text{ DMI of concentrate}_i \\ &\times \text{CP of concentrate}_i (\%)] \end{aligned}$$

where $i = 1, 2, \dots, n$, and n is the number of concentrates.

$$\text{CP req for BW change (kg)} = \text{BW change (kg)} \\ \times \text{CP req (kg of CP/kg of BW change)}$$

where CP req (kg of CP/kg of BW change) = 0.078 kg of CP/kg of BW gain = -0.094 kg of CP/kg of BW lost.

The value of 0.088 kg of CP required per kilogram of milk in the equation of $\text{MF}_{\text{protein}}$ is an adaptation from the protein requirement in the NRC (2001). It was calculated using the MP required by the cow for milk production (0.0472 kg for milk production and 0.0112 kg for the increase in maintenance related to milk production) multiplied by a conversion factor between MP and CP (1.5). The value of MP required to produce 1 kg of milk containing 3.4% CP is directly obtainable in NRC (2001): $(0.034 (\text{CP}) \times 0.93 (\text{true protein/CP}))/0.67 (\text{true protein/MP}) = 0.0472 \text{ kg of MP/kg of milk}$. The maintenance related to milk production (0.0112 kg of MP/kg of milk) was calculated using the portion of DMI imputable to milk production [0.372 kg of DMI/kg of 4% fat-corrected milk; equation 1-2 (NRC, 2001, p 4) in the portion of the equation for predicting MP requirement for maintenance (NRC, 2001, p 68) related to DMI. To make it easier for dairy producers to use, the bacteria MP calculation in the MP requirement for maintenance calculation from the NRC (2001) equation was simplified. When estimating bacteria MP, it was assumed that RDP was not limiting for microbial growth and that the diet contained 66% of adjusted TDN for DMI. The factor of 1.5 to convert MP to CP was evaluated by comparing amount of CP in diets with their resulting MP supplied using typical dairy cattle diets in Quebec formulated with the NRC (2001) software. The PCM equation was calculated by multiplying total milk yield with CP concentration of milk and an adjustment factor ($1/3.4 = 0.294$) to adjust milk yield with different CP concentration to 3.4% CP. The CP for gain or loss of BW is a combination of the percentage of MP/kg of BW change for a cow with a BCS of 3 (NRC, 2001) and the 1.5 conversion factor to convert MP to CP.

$$\text{MF}_{\text{average}} (\text{kg}) = \frac{(\text{MF}_{\text{energy}} (\text{kg}) + \text{MF}_{\text{protein}} (\text{kg}))}{2}$$

The average between $\text{MF}_{\text{energy}}$ and $\text{MF}_{\text{protein}}$, $\text{MF}_{\text{average}}$, gives an estimation of forage use, taking both energy and protein into account.

Calculation of Allowable MF

Allowable MF (AMF) is an estimation of the potential of forage for milk production. Allowable milk from forage energy ($\text{AMF}_{\text{energy}}$) was calculated using the energy content of forage divided by the need of this component for milk production. Similar calculation was used for AMF

protein ($\text{AMF}_{\text{protein}}$) with the CP of forage. Average AMF is the average of $\text{AMF}_{\text{energy}}$ and $\text{AMF}_{\text{protein}}$. They were calculated using the following equations:

$$\text{AMF}_{\text{energy}} = \frac{\sum_{i=1}^n (\text{DMI of forage}_i \times \text{NE}_L \text{ forage}_i) - \text{NE}_L \text{ for maintenance}}{0.75 \text{ Mcal/ kg of milk}}$$

where $i = 1, 2, \dots, n$, and n is the number of forages.

The values of NE_L for forage were calculated using a 74% diet TDN_{1X} with an intake above maintenance at 3X maintenance. Energy requirement for maintenance was calculated using $0.080 \text{ Mcal/ kg BW}^{0.75}$ as suggested in the NRC (2001).

$$\text{AMF}_{\text{protein}} = \frac{\sum_{i=1}^n (\text{DMI of forage}_i \times \text{CP forage}_i) - \text{CP for maintenance}}{0.088 \text{ kg of CP/kg of milk}}$$

where $i = 1, 2, \dots, n$, and n is the number of forages.

Protein requirement for maintenance was calculated using an equation from NRC (2001, p 68) with the same simplifications outlined in $\text{MF}_{\text{protein}}$ calculation:

$$\text{AMF}_{\text{average}} = \frac{(\text{AMF}_{\text{energy}} + \text{AMF}_{\text{protein}})}{2}$$

Because maintenance requirement of cows are attributed to forage both in MF and AMF, comparisons between these 2 concepts are possible. The difference between AMF and MF was calculated for energy, protein, and the average of both. Results from this subtraction represent the gap between the potential for milk production of forage (AMF) and the estimation of how the forage was used for milk production (MF). The smaller the difference is, the better the use of the forage.

Statistical Analyses

Body weight, DMI, blood metabolites, milk yield and composition, and MF were averaged for each cow at each period and subjected to ANOVA using the GLM procedure of SAS 8.2 (SAS, 2001) for a replicated 4×4 Latin square design. Multiple treatment comparisons were made using a Duncan test. Difference between treatments was declared significant when P values were <0.05 . Rumen fluid pH, VFA, and NH_3 N data were subjected to a repeated measurement analysis; time of sampling was the repetition. Data were statistically analyzed using the mixed model procedure of SAS with the repeated statement. As no interaction between time and

Table 2. Chemical composition of forage and experimental diets

Chemical component	Alfalfa silage	Treatment ¹				SEM
		Control	GC	GC+S	GC+W	
DM, %	35.2	49.4	50.7	50.9	50.9	0.43
NE _L , Mcal/kg ²	—	1.56	1.54	1.55	1.54	—
ADF, % of DM	37.2	20.6	18.9	18.0	17.2	0.38
NDF, % of DM	41.7	28.9	27.1	25.1	24.9	0.59
CP, % of DM	21.6	18.7	17.9	17.4	18.0	0.16
RDP, % of DM ²	—	13.7	12.8	12.7	13.0	—
Starch, % of DM ²	5.5	26.7	28.8	33.3	21.6	—
Ash, % of DM	11.7	7.5	6.9	6.7	7.4	0.15

¹Control treatment included cracked corn. GC = ground corn, GC+S = ground corn plus wheat starch, and GC+W = ground corn plus dried whey permeate.

²Estimated for each treatment using the average characteristics of the treatment according to NRC (2001).

treatment was found; treatment effect was tested using a Duncan test.

RESULTS

The alfalfa forage used in this experiment was of average quality, with higher CP but also higher ADF than the average Quebec forage (Table 2). Although there were variations in diet composition, diets were isoenergetic (Table 2). The GC and GC+S diets had lower ash content than the control and GC+W diets. The GC diet had a higher DM and starch content and lower ADF, NDF, CP, and ash concentration as compared with the control diet. When diets were formulated, the only difference between the control and GC diets was the replace-

ment of cracked corn by ground corn (Table 1). Differences in diet composition between the control and GC diets (Table 2) could come from a lower DM content in the cracked corn grain as compared with the ground corn. Equivalent DM content for both corn grains was measured when diets were formulated and mixed. However, lower concentrations of ADF, NDF, CP, and ash and higher DM and starch concentrations in the GC would suggest a higher DM for ground corn. This would imply that even if both diets were supposed to have the same quantity of grain, the control diet might have contained less on a DM basis. Dry matter of each ingredient was measured in an oven during 3 d at 65°C at the beginning of the experiment, but 65°C might have overestimated DM content of cracked corn.

Table 3. Body weight, daily intakes of DM, fibers, and CP; and NRC prediction for ruminally degraded and undegraded protein, metabolizable protein, starch, and energy in cows fed an alfalfa-based diet supplemented with concentrates with different ruminal carbohydrate degradability

Item	Treatment ¹				SEM	P
	Control	GC	GC+S	GC+W		
BW, kg	612	609	615	618	3.3	0.34
BW change, kg/d	0.28	0.70	0.75	0.79	0.175	0.18
DMI, kg/d	22.7 ^c	24.3 ^b	24.4 ^b	25.7 ^a	0.35	<0.001
DMI, % of BW	3.72 ^c	4.00 ^b	3.98 ^b	4.19 ^a	0.059	<0.001
ADF, kg/d	4.73 ^a	4.60 ^a	4.41 ^b	4.42 ^b	0.053	<0.01
NDF, kg/d	6.62 ^a	6.61 ^a	6.10 ^b	6.44 ^a	0.082	<0.01
CP, kg/d	4.26 ^b	4.34 ^b	4.27 ^b	4.63 ^a	0.053	<0.001
RDP, ² g/d	3,068	3,136	3,074	3,170	78.8	0.76
RUP, ² g/d	1,164 ^b	1,252 ^a	1,150 ^b	1,268 ^a	23.7	<0.01
MP, ² g/d	2,291 ^b	2,432 ^a	2,328 ^b	2,455 ^a	32.6	<0.01
MP-bacterial, ² g/d	1,226 ^b	1,292 ^a	1,292 ^a	1,325 ^a	14.6	<0.01
MP-RUP, ² g/d	955 ^b	1,025 ^a	922 ^b	1,012 ^a	16.7	<0.01
Starch, ³ kg/d	6.09 ^c	7.03 ^b	8.13 ^a	5.55 ^d	0.155	<0.001
NE _L , ² Mcal/d	36.0 ^c	37.6 ^{ab}	37.4 ^b	38.6 ^a	0.37	<0.01

^{a,b,c}Means within a row with different superscripts differ.

¹Control treatment included cracked corn. GC = ground corn, GC+S = ground corn plus wheat starch, and GC+W = ground corn plus dried whey permeate.

²Estimated for each cow individually using characteristics and diet of each cow for each period with NRC (2001) software.

³Estimated for each cow individually using the diet of each cow for each period according to NRC (2001).

Table 4. Milk production and composition in cows fed an alfalfa-based diet supplemented with concentrates with different ruminal carbohydrate degradability

Item	Treatment ¹				SEM	P
	Control	GC	GC+S	GC+W		
Milk yield						
Actual, kg/d	34.0 ^c	37.4 ^{ab}	37.6 ^a	35.8 ^b	0.57	<0.01
Energy-corrected, ² kg/d	32.4 ^b	35.2 ^a	34.5 ^a	35.0 ^a	0.57	0.01
Protein-corrected, ³ kg/d	31.8 ^c	36.9 ^a	36.5 ^{ab}	35.0 ^b	0.51	<0.001
Fat						
Concentration, %	3.82 ^{ab}	3.55 ^{ab}	3.49 ^b	3.88 ^a	0.127	0.05
Yield, g/d	1,281	1,310	1,278	1,368	41.5	0.45
Protein						
Concentration, %	3.22	3.33	3.33	3.35	0.040	0.14
Yield, g/d	1,078 ^c	1,234 ^a	1,236 ^a	1,177 ^b	16.5	<0.001
Lactose						
Concentration, %	4.65 ^b	4.72 ^a	4.68 ^b	4.65 ^b	0.013	<0.01
Yield, g/d	1,574 ^b	1,760 ^a	1,750 ^a	1,658 ^b	28.2	<0.001
MUN						
Concentration, mg/dL	13.4 ^a	10.7 ^b	9.9 ^b	9.8 ^b	0.32	<0.001
Efficiency						
NE _L milk/NE _L ingested, ⁴ %	67.75	70.38	67.88	70.13	0.013	0.37
N _{milk} /N _{ingested} , ⁵ %	24.83 ^b	27.86 ^a	28.43 ^a	24.91 ^b	0.473	<0.001

^{a,b,c}Means within a row with different superscripts differ.

¹Control treatment included cracked corn. GC = ground corn, GC+S = ground corn plus wheat starch, and GC+W = ground corn plus dried whey permeate.

²Energy-corrected milk (4% fat, 3.4% protein) = milk $\times$ (0.124% fat + 0.073% CP + 0.256).

³Protein-corrected milk (3.4% protein) = milk $\times$ 0.296% CP.

⁴NE_L milk/NE_L ingested = [ECM (kg of milk) $\times$ 0.75 Mcal/kg of milk]/NE_L ingested (Mcal) estimated with NRC (2001), where ECM = energy-corrected milk.

⁵N_{milk}/N_{ingested} = [milk protein yield (kg)/6.38 (kg of milk protein/kg of N)]/[CP intake (kg)/6.25 (kg of protein/kg of N)].

Dry matter intake expressed as kilograms per day or as a percentage of BW was higher for cows fed GC+W and lower for those fed the control as compared with those fed the GC and GC+S diets (Table 3). The daily intake of nutrients did not always follow the same pattern as total DMI. Because wheat starch and dried whey permeate are low in ADF content, ADF intake was higher for cows fed the control and GC diets. Cows fed the GC+S diet had the lowest NDF intake. Also, lower concentrations of ADF, NDF, and CP in GC compared with the control (Table 2) compensated for the lower DMI of cows fed the control diet. Crude protein intake was higher for cows fed the GC+W diet, which is in accordance with DMI. Estimated RDP supply was not affected by treatment. However, the estimated RUP supply to cows was higher for GC and GC+W than for the control and GC+S, as well as the estimated MP supply to cows. Cows fed GC and GC+W diets had higher estimated MP bacteria than those fed the control diet but not compared with those fed the GC+S diet. Estimated starch intake was in accordance with starch concentration of the diet and DMI, cows fed GC+W had the lowest starch intake, and cows fed GC+S had the highest starch intake. Cows fed the control diet had the lowest esti-

mated NE_L supply. The GC+W provided more NE_L than GC+S, and the GC provided an intermediate value. Although the control cows had a numerically lower BW change, there was no significant difference between treatments for BW change and BW (Table 3).

Treatments GC and GC+S led to an increase of 3.5 kg of milk/d over production of cows on the control diet; the GC+W diet resulted in an intermediate increment (Table 4). The 3 treatments similarly increased ECM, which considers fat and protein concentrations in milk (Table 4), and PCM, which considers protein in milk (Table 4). Milk fat concentration was highest for GC+W and lowest for GC+S; the control and GC diets had intermediate values. Fat yield was not affected by treatments (Table 4). Protein concentration of milk was similar for all treatments. Protein yield followed the same pattern as milk yield and was higher for GC and GC+S, followed by GC+W and finally by the control diet (Table 4). Lactose concentration was the highest for the GC treatment. Lactose yield was greater for GC and for GC+S than for the control and GC+W treatments (Table 4). Milk urea N was higher with the control diet (Table 4) compared with all other treatments. The efficiency of energy use was not increased by treatments, but the N efficiency

Table 5. Ruminal fermentation parameters in cows fed alfalfa-based diet supplemented with concentrates with different ruminal carbohydrate degradability

Item	Treatment ¹				SEM	P
	Control	GC	GC+S	GC+W		
pH	6.50	6.41	6.41	6.51	0.043	0.28
Total VFA, mM	66.5 ^b	77.2 ^a	77.4 ^a	69.9 ^b	1.69	0.01
Acetate, mM	45.3 ^b	49.5 ^a	48.7 ^{ab}	44.8 ^b	1.12	0.06
Propionate, mM	14.9 ^b	20.2 ^a	21.9 ^a	16.1 ^b	1.09	0.01
Butyrate, mM	6.3	7.5	6.8	9.0	0.74	0.16
Acetate:propionate	3.38 ^{ab}	3.06 ^{ab}	2.43 ^b	3.57 ^a	0.290	0.12
Acetate, mM/100 mM of VFA	69.5 ^a	66.9 ^{ab}	64.4 ^b	67.3 ^{ab}	0.90	0.04
Propionate, mM/100 mM of VFA	21.7 ^b	24.4 ^{ab}	27.4 ^a	21.3 ^b	1.04	0.02
Butyrate, mM/100 mM of VFA	8.9 ^b	8.7 ^b	8.2 ^b	11.4 ^a	0.66	0.05
NH ₃ N, mM	10.1 ^a	8.7 ^{ab}	4.9 ^b	5.4 ^b	1.25	0.07

^{a,b}Means within a row with different superscripts differ.

¹Control treatment included cracked corn. GC = ground corn, GC+S = ground corn plus wheat starch, and GC+W = ground corn plus dried whey permeate.

was higher for the GC and GC+S treatments than for the control and GC+W treatments.

There was no interaction of time by treatment for rumen pH ($P = 0.99$). Average rumen pH was not affected by treatment (Table 5). Rumen pH always remained >6.2 , which is optimal for bacterial fermentation. There was no interaction of time by treatment for total VFA concentrations ($P = 0.99$) or VFA taken individually as a concentration ($P \geq 0.98$) or as a ratio to total VFA ($P \geq 0.99$). Average total VFA was higher for GC and for GC+S (Table 5); both of them had higher propionate, and GC tended to have higher acetate as well (Table 5). Treatments did not impact butyrate (Table 5). The GC+S treatment decreased acetate and increased propionate ratio to total VFA compared with the control (Table 5). Acetate:propionate was lower for GC+S than for GC+W; the control and GC diets showed intermediate values (Table 5). The GC+W treatment had similar propionate but higher butyrate ratio to total VFA than did the control treatment (Table 5). There was also no significant ($P = 0.77$) interaction of time by treatment for NH₃ N. However, average rumen fluid NH₃ N was higher for the control diet than for the GC+S and GC+W diets; the GC diet yielded intermediate values (Table 5).

No changes in plasma NEFA were observed before feeding, but variations were detected after feeding (Table 6). Concentrations of NEFA were higher in cows fed the control diet compared with those fed the GC+S diet (Table 6), which indicates greater adipose tissue mobilization for cows fed the control diet. Treatments had no impact on plasma glucose concentration (Table 6). The plasma urea N (PUN) level was greater for cows fed the control diet in pre- and postfeeding (Table 6). Also, compared with GC, the GC+S and GC+W diets led to a lower PUN (Table 6).

Average MF was higher for GC and for GC+S compared with the control diet (Table 7), reflecting higher MF_{protein} for these 2 treatments. No differences were observed between treatments for MF_{energy} (Table 7). Forages were not used to their full potential; the difference between (AMF-MF)_{average} was, on average, 4.5 kg/d (Table 7). On average, MF_{energy} was 4 kg/d lower than AMF_{energy}, and MF_{protein} was 5 kg/d lower than AMF_{protein} (Table 7). The GC and GC+S treatments increased forage use as compared with the control and GC+W diets, as the difference between AMF and MF on a protein basis was lower for the latter 2 treatments (Table 7).

DISCUSSION

Impact of Corn Grinding or the Use of Wheat Starch

The impact of corn grinding and higher carbohydrate degradability on DMI is not constant among studies. In the present experiment, both GC and GC+S increased DMI compared with the control diet (Table 3). Ekinici and Broderick (1997) obtained an increase in DMI with the processing of high-moisture ear corn. Most other studies on corn grinding did not report higher DMI (Knowlton et al., 1996; Wilkerson et al., 1997; Dhiman et al., 2002). Aldrich et al. (1997) observed a lower DMI with high nonstructural carbohydrate degradability diets, but Lykos et al. (1997) and Broderick et al. (2002) did not. Higher DMI for cows fed GC and GC+S compared with the control diet might have come from lower NDF content and higher ruminal digestibility of diet, both factors known to have an impact on DMI (Ketelaars and Tolcamp, 1992; Mertens, 1994; Allen, 1996). Feed digestibility was not determined, but corn grinding should increase starch digestibility compared with cracking (Knowlton et al., 1996; Wilkerson et al., 1997).

Table 6. Plasma parameters in cows fed an alfalfa-based diet supplemented with concentrates with different ruminal carbohydrate degradability

Item	Treatment ¹				SEM	P
	Control	GC	GC+S	GC+W		
NEFA, $\mu\text{Eq/L}$						
Prefeeding	142.2	128.6	117.0	128.7	8.05	0.22
Postfeeding	119.9 ^a	113.3 ^{ab}	105.9 ^b	112.2 ^{ab}	3.01	0.04
Post – pre ²	–22.3	–15.3	–11.1	–16.5	7.51	0.77
Average	131.0 ^a	120.9 ^{ab}	111.4 ^b	120.5 ^{ab}	4.77	0.07
Glucose, mM						
Prefeeding	3.5	3.4	3.5	3.5	0.08	0.72
Postfeeding	3.3	3.4	3.5	3.3	0.10	0.55
Post – pre	–0.2	0.0	–0.1	–0.2	0.12	0.54
Average	3.4	3.4	3.5	3.4	0.07	0.67
PUN, ³ mM						
Prefeeding	10.4 ^a	9.0 ^b	8.0 ^c	7.5 ^c	0.30	<0.001
Postfeeding	11.2 ^a	9.1 ^b	7.8 ^{bc}	7.4 ^c	0.45	<0.001
Post – pre	0.7	0.2	–0.1	–0.2	0.35	0.28
Average	10.8 ^a	9.1 ^b	7.9 ^c	7.4 ^c	0.34	<0.001

^{a,b,c}Means within a row with different superscripts differ.

¹Control treatment included cracked corn. GC = ground corn, GC+S = ground corn plus wheat starch, and GC+W = ground corn plus dried whey permeate.

²Post – pre = postfeeding minus prefeeding.

³PUN = Plasma urea nitrogen.

In addition, diets with high ruminal availability of carbohydrates would also have a higher nonstructural carbohydrate digestibility compared with diets with low rumen-available carbohydrates (Aldrich et al., 1997).

Estimated increased MP and energy supply (Table 3) resulted in higher milk production and PCM for GC and GC+S compared with the control diet (Table 4), in agreement with other studies where corn processing increased milk production (Knowlton et al., 1996; Wilkerson et al., 1997; Dhiman et al., 2002). The increase in starch content of the GC+S diet over the GC diet (Table

3) did not increase milk production. As milk protein concentration was not affected by the diets, protein yield increased with corn grinding or by using carbohydrates of higher degradability in the rumen, as already reported (Wilkerson et al., 1997; Broderick et al., 2002; Dhiman et al., 2002). The higher efficiency of N use (Table 4) supports the hypothesis of a better use of N from forage, which would result in an increase in $\text{MF}_{\text{protein}}$ and eventually $\text{MF}_{\text{average}}$. The N ingested was better used for milk production for these 2 treatments. The marginal increment in N efficiency from MP to milk in GC and GC+S,

Table 7. Milk from forage and allowable milk from forage in cows fed an alfalfa-based diet supplemented with concentrates with different ruminal carbohydrate degradability

Item	Treatment ¹				SEM	P
	Control	GC	GC+S	GC+W		
$\text{MF}_{\text{energy}}$, ¹ kg/d	0.5	2.9	2.0	1.4	1.51	0.73
$\text{MF}_{\text{protein}}$, ² kg/d	10.5 ^b	14.5 ^a	15.1 ^a	12.0 ^b	0.52	<0.001
$\text{MF}_{\text{average}}$, ³ kg/d	5.5 ^b	8.7 ^a	8.6 ^a	6.7 ^{ab}	0.94	0.08
$(\text{AMF} - \text{MF})_{\text{energy}}$, ⁵ kg/d	4.0	2.9	3.8	5.4	1.70	0.78
$(\text{AMF} - \text{MF})_{\text{protein}}$, ⁶ kg/d	5.9 ^b	3.5 ^a	3.0 ^a	7.5 ^b	0.72	<0.01
$(\text{AMF} - \text{MF})_{\text{average}}$, ⁷ kg/d	5.0	3.2	3.4	6.5	1.16	0.21

^{a,b}Means within a row with different superscripts differ.

¹Control treatment included cracked corn. GC = ground corn, GC+S = ground corn plus wheat starch, and GC+W = ground corn plus dried whey permeate.

² $\text{MF}_{\text{energy}}$ = Milk from forage on an energy basis.

³ $\text{MF}_{\text{protein}}$ = Milk from forage on a protein basis.

⁴ $\text{MF}_{\text{average}}$ = Average milk from forage.

⁵ $(\text{AMF} - \text{MF})_{\text{energy}}$ = Allowable milk from forage energy minus milk from forage on an energy basis.

⁶ $(\text{AMF} - \text{MF})_{\text{protein}}$ = Allowable milk from forage protein minus milk from forage on a protein basis.

⁷ $(\text{AMF} - \text{MF})_{\text{average}}$ = Average allowable milk from forage minus average milk from forage.

using the control diet as a comparison, was, respectively, 111% $[(1,234 \text{ g/d} - 1,078 \text{ g/d})/(2,432 \text{ g/d} - 2,291 \text{ g/d}) \times 100$; combining data from Tables 3 and 4] and 427%. This implies that there was more N used for milk protein than the increase in N from MP of these diets. Increased efficiency may come from a better use of amino acids and/or from a combination with the increased energy supply. The increase in starch intake (Table 3) and the higher nonstructural carbohydrate digestibility of ground corn compared with cracked corn could also partly explain the results in milk production (Moe et al., 1973; Dhiman et al., 2002). However, the site of digestion would likely be accountable for the increase in milk production observed with our high RDP diets, as ruminal degradability of carbohydrates is higher for ground corn (Cerneau and Michalet-Doreau, 1991). Using carbohydrates of higher degradability in the rumen can lead to higher milk production (Lykos et al., 1997; Wilkerson et al., 1997; Dhiman et al., 2002).

Most studies did not report higher total VFA, but did report lower acetate and higher propionate concentrations in rumen fluid with carbohydrates of higher degradability (Lykos et al., 1997; Broderick et al., 2002; Dhiman et al., 2002). Lower acetate:propionate has been associated with lower milk fat concentration (Weimer et al., 1996). In our study, milk fat concentration (Table 4) followed the same pattern as acetate:propionate, with, as a final result, no variation in fat yield, as previously reported (Lykos et al., 1997; Broderick et al., 2002; Dhiman et al., 2002). Lower NEFA with higher carbohydrate degradability (Table 6) is in accordance with other studies (Knowlton et al., 1996; Lykos et al., 1997). Altogether, increases in total VFA (Table 5), N use (Table 4), milk production (Table 4), and ECM (Table 4), as well as lower NEFA (Table 6), point to a better energy use in the rumen with GC and GC+S compared with the control.

Increased use of RDP supplied from forage sources by feeding carbohydrates of higher degradability resulted in higher $\text{MF}_{\text{protein}}$ (Table 7) and led to a tendency for higher $\text{MF}_{\text{average}}$ (Table 7). Together, lower NH_3 N and higher VFA concentrations in rumen fluid (Table 5) and lower PUN (Table 6) and MUN (Table 4) demonstrated an increase in ruminal fermentation with GC and GC+S compared with the control. In addition, the use efficiency of N was increased with those 2 treatments (Table 4). Lower NH_3 N in rumen fluid is presumably the consequence of an increased N use for microbial growth. This increase in N use for microbial growth is typical of feeding smaller corn particle size (Ekinici and Broderick, 1997; Dhiman et al., 2002; Sannes et al., 2002) or more degradable carbohydrate sources (Lykos et al., 1997; Broderick et al., 2002), which increased microbial protein synthesis (Chamberlain and Choung, 2002). The increase in estimated MP supplied by microbial protein

(MP-bacterial) for GC and GC+S (Table 3) compared with the control supports this contention. Also, increased VFA concentrations would result in higher absorption of VFA, a source of energy from the diet to the animal.

Impact of Dried Whey Permeate

The highest DMI was obtained with WHEY treatment (Table 3). Higher than control DMI are common (Schingoethe, 1976; Casper and Schingoethe, 1986; Casper and Schingoethe, 1989) but not invariably higher (Schingoethe and Skyberg, 1981a,b) when whey by-products are included in dairy diets. The increment in DMI could be largely attributed to the high palatability of whey products (Schingoethe, 1976).

Lower milk yield for WHEY compared with GC or GC+S (Table 4) could be associated with whey product peculiarities in the rumen. Whey products have a high mineral content (Schingoethe et al., 1980; Windschitl and Schingoethe, 1984). In this trial, dried whey permeate had 6.61% ash on a DM basis as compared with 0.07% for wheat starch. High mineral content increase water consumption (Windschitl and Schingoethe, 1984), volume (Windschitl and Schingoethe, 1984), osmolality (Rogers et al., 1979), and dilution rate of ruminal fluid (Windschitl and Schingoethe, 1984). High DMI is also known to augment dilution rates (Owens and Goetsch, 1986). Increased dilution rate influences rumen fermentation; molar proportion of butyrate usually increased (Rogers et al., 1982; Windschitl and Schingoethe, 1984), but the molar proportion of propionate often decreased (Rogers et al., 1979, 1982; Windschitl and Schingoethe, 1984). In this study, molar proportions of VFA were influenced in this fashion with GC+W compared with GC or GC+S (Table 5). Also, lactose fermentation yields different proportions of VFA compared with starch (Schingoethe, 1976; Casper and Schingoethe, 1986, 1989). Lactose fermentation favors the production of butyrate instead of propionate when used by microorganisms (Defraín et al., 2004). In our trial, variations in VFA concentrations and profiles (Table 5) were associated with lower milk production (Table 4), lower total protein and lactose yields (Table 4), and higher milk fat concentration (Table 4) for GC+W compared with GC and GC+S. Other studies using whey products reported similar results, and milk production was usually comparable with that of the control diets (Schingoethe, 1976; Casper and Schingoethe, 1986, 1989); fat concentration was higher (Schingoethe, 1976; Casper and Schingoethe, 1989). However, Casper and Schingoethe (1986) did not record any significant variations in milk fat concentration with the use of dried whey. Fat yield was not affected by treatment, as there was lower milk yield but higher fat concentration for GC+W compared with GC and

GC+S (Table 4). Similar ECM results (Table 4) point to the equivalent energy needs to produce milk for GC, GC+S, and GC+W, even if quantities and composition differed.

In contrast with GC and GC+S, GC+W did not improve the efficiency of N use (Table 4). The lack of response in the efficiency of N use with GC+W is also associated with the lack of response for MF_{protein} and MF_{average} (Table 7). Whey products are mostly composed of lactose, highly degraded in the rumen (King and Schingoethe, 1983), which allows better NH_3 N use (Schingoethe et al., 1980). Lower levels of MUN (Table 4), rumen NH_3 N (Table 5), and PUN (Table 6) confirm the better use of N in the rumen with GC+W in this trial. The similar level of MF_{energy} , MF_{protein} , and MF_{average} (Table 7) with this increase in N use in the rumen could be attributed to the increase in DMI (Table 3). Because more N was ingested (Table 3), the N efficiency (Table 4) and MF_{protein} (Table 7) did not respond as they did for GC and GC+S. The increase in milk production and PCM (Table 4) with GC+W compared with the control was not enough to compensate for the increase in DMI (Table 3), which explains the similar results in efficiency for those 2 treatments.

Forage Use

Because the calculations of MF assume that the energy and protein supplied by forages and concentrates are additive and considers that concentrates are fully used by the cow for milk production, only the proportion of milk that could not be theoretically produced by the concentrates is attributed to forage (Charbonneau et al., 2003). This makes MF a useful management tool to estimate how the forages are used for milk production. It differs from AMF and other models such as Milk 2000 (Schwab et al., 2003), which consider the potential for milk production from forage. The differences between AMF and MF (Table 7) showed that the forages were not used to their full potential. Low MF and differences between AMF and MF (Table 7) result from too many concentrates in the diets. In this experiment, high-concentrate diets were served, as there was an underestimation of the DMI when the experiment was planned using NRC (2001) software. The lower difference between AMF and MF on a protein basis for GC and GC+S suggested that the forage was used more efficiently with these 2 treatments as compared with the control and the GC+W. Because treatments tested the hypothesis of a better use of forage RDP with higher rumen carbohydrate degradability, these results confirm the importance of a better combination of concentrates and forages.

CONCLUSIONS

Results of this study indicated that the use of carbohydrates of higher degradability improved animal performances and the production of MF with a dairy alfalfa silage-based diet. Milk from forage on a protein basis increased through a better use of RDP. Grinding corn instead of cracking improved forage use as observed with lower $(AMF-MF)_{\text{protein}}$ and improved MF and milk production. Partial substitution of ground corn with different sources of nonstructural carbohydrates, such as wheat starch or dried whey permeate, did not achieve better results than ground corn.

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