Supplemental Carbohydrate Sources for Lactating Dairy Cows on Pasture

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ABSTRACT

Two experiments were conducted to evaluate steam-flaked corn and nonforage fiber sources as supplemental carbohydrates for lactating dairy cows on pasture. Cows were allotted to a new paddock of an orchardgrass (*Dactylis glomerata* L.) pasture twice daily in one group in both trials. In experiment 1, 28 Holstein cows, averaging 216 d in milk, were randomly assigned to either a cracked-corn (CC) or a steam-flaked (SFC) supplement in a split plot design. The supplement contained 66.7% of corn and a protein/mineral pellet. In experiment 2, 28 Holstein cows, averaging 182 d in milk, were randomly assigned to either a ground corn (GC) or a nonforage fiber (NFF)-based supplemented in a single reversal design. The GC supplement contained 85% ground corn plus protein, mineral, and vitamins. The NFF supplement contained 35% ground corn, 18% beet pulp, 18% soyhulls, 8% wheat middlings plus protein, mineral, and vitamins. In both experiments, cows were fed the grain supplement twice daily after each milking at 1 kg/4 kg milk. In experiment 1, milk production (24.3 kg/d) and composition did not differ between treatments; however, plasma and milk urea N were lower with the SFC supplement. In experiment 2, milk production (27.5 kg/d) was not affected by treatments, which may be related to the medium quality of pasture grazed. The GC supplement tended to reduce plasma and milk urea N and increased milk protein percentage (3.23 vs. 3.19%). Pasture dry matter intake, measured using Cr₂O₃, did not differ between treatments in either experiment 1 (15.1 kg/d) or experiment 2 (12.2 kg/d). Milk production did not differ when mid-late lactation cows on pasture were supplemented with SFC or NFF instead of dry corn.

(Key words: grazing dairy cow, steam-flaked corn, nonforage fiber source, milk)

Abbreviation key: CC = cracked corn, GC = ground corn, FO = fecal output, IVDMD = in vitro dry matter digestibility, MUN = milk urea nitrogen, NFF = nonforage fiber, SFC = steam-flaked corn.

INTRODUCTION

Narrow profit margins and low profitability have contributed to the adoption of low cost, pasture-based systems managed intensively to improve profitability and reduce feed costs (Clark and Kanneganti, 1998). However, milk production per cow is frequently lower in a pasture-based system (Muller and Fales, 1998). Proper supplementation strategies are needed to maintain profitable milk production and to minimize the decrease in milk production with intensive grazing.

Pasture, as the sole diet, does not meet nutrient requirements for high producing dairy cows (Kolver and Muller, 1998). Two factors that limit milk production on pasture are low DMI (Bargo et al., 2003) and a high content of highly degradable CP in relation to NSC (Carruthers et al., 1997). Corn, a common supplement fed to grazing cows, provides supplemental energy and increases total DMI compared with pasture only (Bargo et al., 2002; Muller and Fales, 1998). Supplements such as steam-flaked corn (SFC) and nonforage fiber (NFF) sources may provide benefits over corn. Steam-flaking of corn increases the ruminal availability of carbohydrate and decreases the ruminal availability of protein compared to cracked-corn (CC) or ground corn (GC; Joy et al., 1997; Lykos et al., 1997; Yu, 1998), providing a supplemental energy source more complementary to pasture and increasing N utilization. Concentrate supplements that are high in fiber such as beet pulp and soyhulls, known as NFF sources, have increased pasture DMI and milk production (Meijs, 1986; Spörndly, 1991; Sayers, 1999).

Two experiments were conducted with the objective to evaluate the partial replacement of dry corn (CC or GC) by SFC (experiment 1) or NFF (experiment 2) supplements on DMI, milk production, milk composition, BW, and blood and urine metabolites.

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Experiment 1

Twenty-eight Holstein cows [milk yield, 33.5 ± 3.6 kg/d; DIM, 216 ± 35 ; BCS, 2.97 ± 0.57 (mean $\pm$ SD)] were paired according to milk production, stage of lactation, and BCS, and randomly assigned within pairs to a CC or a SFC supplement with pasture as the sole forage during the fall. Cows were adjusted from a TMR-based ration to an intensive grazing system during a 2-wk period by grazing during the day and feeding a TMR at night. During the last 3 d of the adjustment period, cows received pasture as the sole forage along with the supplemental concentrates.

All cows grazed 8.5 ha consisting primarily of orchardgrass (*Dactylis glomerata* L.) and received supplemental treatments for a 6-wk experimental period. Herbage mass per hectare was measured twice weekly by randomly cutting five quadrats to ground level and drying for 48 h at 100°C in a forced air oven to determine DM content. Area allotted daily was then adjusted for a targeted herbage allowance of 40 kg of DM/cow per day in order to maximize pasture DMI. All cows grazed in one group and were rotated to a new paddock twice daily after each milking. Supplements were individually fed twice daily after each milking and refusals were weighed daily. The amount of concentrate fed was determined before the start of the trial using a guideline of 1 kg/4 kg of milk and was held constant for the 6-wk experimental period. Concentrate supplements contained 67% of CC or SFC plus a protein/mineral pellet (Table 1). Diets were balanced according to NRC (1989) recommendations with estimates of pasture DMI and quality based on previous studies (Muller and Fales, 1998).

Cows were milked twice daily at 0600 and 1700 h and yield was measured at each milking and averaged by week. Milk samples were obtained 2 d each week at a.m. and p.m. milking, preserved with 2-bromo-2-nitropropane-1, 3 diol, and analyzed for milk fat, milk protein, and milk urea N (MUN) by infrared spectrophotometry (Foss 605 Milko-scan; Foss Electric, Hillerød, Denmark) at the Pennsylvania DHI testing lab. Milk composition data was averaged by week. Body weight was measured 2 d consecutively at wk 0, 2, 4, and 6. Three independent observers evaluated BCS at wk 1, 2, 4, and 6 using a scale from 1 to 5 (1 = thin and 5 = fat; Wildman et al., 1982).

Experiment 2

Twenty-eight Holstein cows [milk yield, 33.5 ± 3.9 kg/d; DIM, 182 ± 31 ; BCS, 2.90 ± 0.48 (mean $\pm$ SD)] were paired according to milk production, stage of lactation, and BCS, and within pairs randomly assigned to either a GC or a NFF-based supplement with pasture

as the sole forage. Beet pulp and soy hulls replaced some GC in the NFF treatment. Cows grazed in one group during May and June for a 28 d period (period 1), and then switched treatments for 28 d (period 2) in a single reversal design. Periods 1 and 2 each consisted of a 7-d adjustment period and a 21-d period for experimental measures. Cows were adjusted from a TMR-based confinement system to management intensive grazing over a 4-wk period. Cows were fed a TMR at night and grazed during the day. Seven days prior to the start of period 1, cows received the experimental treatments, and grazed day and night with pasture as the sole forage.

Cows grazed 11 ha consisting primarily of orchardgrass (*Dactylis glomerata* L.). Herbage mass measurements and targeted herbage allowance were similar to experiment 1. All cows grazed in one group and were rotated to a new paddock twice daily after each milking. At the end of the first period, pasture growth had slowed due to adequate rainfall and sufficient grass from pasture was not available in proximity to the milking center. Therefore, pasture was cut and carried to the cows for 7 d during the adjustment between periods 1 and 2 and during the first 11 d for period 2. Pasture was harvested with a flail harvester and fed ad libitum twice daily in a free-stall barn. Cows returned to pasture during the last 10 d of period 2 when adequate pasture regrowth occurred. Area allotted per day was adjusted to an average herbage allowance of 40 kg of DM/cow per day.

Supplements were individually fed twice daily after each milking at a rate of 1 kg of concentrate/4 kg of milk, and refusals were weighed daily. The level fed was determined at the time of pairing the cows and before the adjustment period, and was constant for both experimental periods during the 56-d trial. Ingredient composition of supplements is shown in Table 1. Supplements were formulated to balance diets according to NRC (1989) recommendations with estimates of pasture DMI and quality based on previous studies (Muller and Fales, 1998). Procedures for milking, milk sampling and testing, BW, and BCS were similar to those described for experiment 1.

Experimental Procedures

In experiment 1, the corn was processed by Pennfield Corp. (Rohrerstown, PA). The SFC had a density of 0.36 kg/L. A 150 HP Hammermill was used to prepare the CC. Corn samples were dry sieved for 2 min with the Fritsch Analysette 3 pro oscillating sieve shaker (Fritsch, Oberstein, Germany). Particle size distribution for CC was 7.33, 18.46, 22.10, 26.57, 11.30, 4.14, and 10.10% of particles and for SFC was 23.66, 39.35,

Table 1. Ingredient composition of cracked-corn (CC), steam-flaked corn (SFC), ground corn (GC), and nonforage fiber (NFF) supplements.

Item	Experiment 1		Experiment 2	
	CC	SFC	GC	NFF
	% DM			
Cracked corn	66.50	...	...	...
Steam-flaked corn	...	66.50	...	...
Ground corn	...	...	70.23	34.76
Beet pulp	...	...	...	17.96
Soybean hulls	10.60	10.60	...	17.38
Wheat middlings	10.60	10.60	7.84	8.11
Soybean meal	...	...	7.84	8.11
Soy Pass ¹	2.00	2.00	...	...
Corn dried distillers	...	...	1.74	5.79
Molasses	1.20	1.20	5.80	5.79
Tallow	1.10	1.10	...	...
Sodium bicarbonate	1.87	1.88	...	...
Dicalcium phosphate	1.70	1.70	2.32	2.32
Limestone (37% Ca)	1.60	1.60	1.16	0.58
Salt	1.32	1.32	1.45	1.45
Dynamate ²	0.43	0.43	0.52	0.52
Magnesium oxide	0.43	0.43	0.93	0.81
Zinpro ³	0.22	0.22	...	...
Selenium premix (0.06) ⁴	0.11	0.11	0.17	0.17
Ruminate TMP ⁵	0.06	0.06	...	...
ADE Vitamin pre-mix ⁶	0.06	0.06	...	...
PS TM premix (#4) ⁷	0.20	0.20	0.23	0.23

¹Linotech Inc. (Overland Park, KS), contained: 53.4% CP.

²Agway, Inc. (Syracuse, NY), contained: 18% K, 11% Mg, and 22% S.

³Zinpro Corp. (Edina, MN).

⁴Agway, Inc. (Syracuse, NY), contained: 0.06% Se.

⁵Pennfield Corp. (Rohersstown, PA).

⁶Contained 1.36 million IU/kg of vitamin A; 454,545 IU/kg of vitamin D; and 1363 IU/kg of vitamin E.

⁷Contained 25.3% Ca; 5.8% S; 11,111 ppm Cu; 303 ppm Co; 13,535 ppm Fe; 909 ppm I; 20,202 ppm Mn; and 58,589 ppm Zn.

13.99, 12.62, 4.22, and 6.16% of particles on the 4.75, 3.35, 2.36, 1.18, 0.60, and < 0.60-mm screens, respectively.

For both experiments, samples of supplemental grains were collected daily, composited weekly, and subsequently dried for 48 h at 55°C with a forced-air oven. Pasture samples were hand plucked at the approximate level that cows grazed, stored at -20°C, and subsequently freeze-dried. Daily collection was made for both supplements and pasture during d 6 to 10 of the intake periods. Supplements and pasture were ground through 1-mm screen (Wiley Mill, Arthur H. Thomas, Philadelphia, PA), and analyzed for DM, CP, NDF, ADF, ether extract, and ash (AOAC, 1990), soluble protein (Krishnamoorthy et al., 1982), degradable protein (Krishnamoorthy et al., 1983), in vitro DM digestibility (IVDMD; Ankom Daisy II, ANKOM Technology Corp., Fairport, NY), and NSC (Smith, 1981; modified to use potassium ferricyanide). Mineral composition was determined by wet chemistry at Dairy One Forage Testing Lab (Ithaca, NY).

Supplements for experiment 1 and 2 were evaluated to determine rumen availability and rumen degradation of DM, NSC, and N. Two ruminally cannulated cows were housed indoors and were fed with fed fresh cut pasture plus the two supplements from each experiment. The in situ evaluation for each experiment supplements was run as a single reversal with two periods, where each cow was fed a different supplement in each period. Approximately 5 g DM of each supplement (1-mm ground) were placed into previously dried bags (at 55°C in a forced air oven) with a mean pore size of 52 μ m. The bags were then closed with a plastic tie 2 cm below the top, resulting in an effective surface area of 10 $\times$ 20 cm. The sample to surface area ratio was about 25 mg DM/cm². Bags were tied to the end a 100-cm nylon line and incubated for 0, 1, 2, 4, 8, 16, 24, and 48 h after being soaked in 39°C distilled water for 15 min. Triplicate bags were incubated for the 24 and 48 h time points and duplicate bags for all other time points. Alfalfa hay standard (4-mm ground) was incubated in duplicate bags for 2, 8, 16, and 24 h, and monitored for

variation between and among cows. The degradability of the standard was within the range observed in previous experiments (Bargo et al., 2002). Bags were inserted into the rumen in reverse order and were retrieved at 0 h, rinsed in cold water for 30 to 40 s per bag, and washed in a washing machine. Bags were dried at 55°C for 48 h and the residue ground through a 1-mm screen (Wiley Mill, Thomas Scientific, Philadelphia, PA). A composite was made of triplicate or duplicate residues at each time point within cow and analyzed for DM, N, ash (AOAC, 1990), and NSC (Smith, 1981; modified to use ferricyanide as the colorimetric indicator). Effective rumen degradability and fractional degradation rate of DM, NSC, and N in the rumen were calculated using a nonlinear model according to Ørskov and McDonald (1979). The Marquardt method (SAS, 1985) was used to fit the model: $P = A + B(1 - e^{-ct})$, where:

P = disappearance, %;
 A = soluble fraction, %;
 B = potentially degradable fraction, %;
 c = fraction rate of degradation, %/h; and
 t = time (h).

Effective ruminal degradability (ERD) of DM, NSC, and N were calculated using the equation: $ERD = A + B[c/(c + k)]$, where k = rate of passage assumed (6%/h).

Pasture Intake

Pasture DMI was estimated using Cr_2O_3 , an indigestible fecal marker, during wk 2 and 5 for eight cows on each treatment in experiment 1, and during wk 4 and 8 for 13 cows on each treatment during experiment 2. Cows were dosed twice daily with Cr_2O_3 at 5 g/dosing (10 g/d) for 10 d, and fecal grab samples were obtained twice daily from d 7 to 11. Fecal samples were frozen and composited for each cow and analyzed for Cr content (Parker et al., 1989) to determine the fecal output (FO, g/d): $FO = (g\ Cr/d)/(g\ Cr/g\ fecal\ DM)$. Total DMI was determined using the equation: $DMI = fecal\ output / (1 - IVDMD)$. Pasture DMI was determined using measured supplement DMI: $Pasture\ DMI = total\ DMI - supplement\ DMI$. Pasture DMI estimates were further refined through weighting IVDMD and recalculating pasture DMI.

Blood and Urine Metabolites

Blood samples were obtained from the coccygeal vessels during wk 2, 4, and 6 at 0630 h after milking and before supplement feeding in experiment 1. In experiment 2, samples were obtained during the last 2 wk of each period. Approximately 10 ml of blood was collected

into two evacuated tubes containing sodium heparin and one tube containing potassium oxalate-sodium fluoride (glycolytic inhibitor). Tubes containing blood were immediately placed in ice. Samples were transported to a laboratory and centrifuged at $3000 \times g$ for 15 min at 4°C. Plasma was then collected and stored at -20°C. Plasma was analyzed for plasma urea N (Stanbio Urea Nitrogen kit 580, Stanbio Laboratory, Inc., San Antonio, TX), NEFA (Wako NEFA C Kit, Bio Diagnosis Inc., Edgewood, NY), and glucose (Sigma Glucose kit 510, Sigma Chemical Co., St. Louis, MO).

In experiment 2, spot samples of urine were collected by vulval stimulation after the a.m. milking during the last 2 d of each experimental period. Urine was treated with 1 N HCl to keep pH below 2. Samples were frozen and stored at -20°C until analyzed. Urine samples were thawed and analyzed for creatinine (Sigma kit number 555-A; Sigma Chemical Co., St. Louis, MO) and allantoin (Chen, 1989) for an estimate of ruminal microbial synthesis (Bargo et al., 2002).

Statistical Analysis

The experimental design for experiment 1 was a split plot design and data were analyzed with the general linear models of SAS (1985): $Y = Treatment + Cow (Treatment) + Week + Treatment \times Week + Error$. Cow (Treatment) was used as the error term to test the effect of treatment. The interaction between treatment $\times$ week was not significant for any of the variables analyzed. The experimental design for experiment 2 was a single reversal design and data were analyzed with the general linear model procedures of SAS (1985) with the model: $Y = Treatment + Period + Cow + Error$.

RESULTS AND DISCUSSION

Experiment 1

Herbage mass from wk 1 to 6 was 2330, 2300, 2740, 2620, 1990, and 2090 kg of DM/ha, respectively, and averaged 2400 kg of DM/ha (SE 124 kg DM/ha). Area allotted per day was adjusted to an herbage allowance of 38.4 kg of DM/cow per day compared to the target of 40 kg DM/cow per day. Pasture was of high quality, averaging 24% CP, 46% NDF, and 67% IVDMD (Table 2). Chemical composition was within ranges described for this type of pastures (Muller and Fales, 1998). The chemical composition of the pasture, the two types of corn, and the protein/mineral pellet are presented in Table 2. Neutral detergent fiber was lower and NSC was higher for SFC compared to CC. Both supplements were similar in CP, soluble protein, degradable protein content, and high in IVDMD (>86%). Estimated nutri-

Table 2. Chemical composition of pasture and supplements (experiments 1 and 2).

Item	Experiment 1				Experiment 2		
	Pasture	Supplement			Pasture	Supplement	
		CC	SFC	Pellet ¹		GC	NFF
				% DM			
OM	91.6	90.7	91.2	86.5	91.6	90.2	89.7
CP	24.1	7.8	6.8	12.6	19.6	13.1	12.9
Soluble protein, % CP	32.4	11.4	8.7	13.6	29.2	17.8	18.5
Degradable protein, % CP	77.4	31.6	23.9	47.6	59.5	35.5	37.3
NDF	45.7	11.3	8.1	35.0	51.8	14.5	29.5
ADF	26.3	3.2	2.9	21.0	28.5	5.9	17.0
NSC	14.6	70.6	76.4	22.5	18.1	60.6	42.3
Ether extract	4.1	3.6	2.0	4.0	3.7	2.1	2.2
NDF-IP ² , %CP	20.2	...	...	...	22.0	...	...
IVDMD ³	66.8	86.1	87.7	79.5	64.1	85.0	79.8
NE _L , ⁴ Mcal/kg	1.65	1.85	2.05	1.56	1.65	1.81	1.76
Ca	0.47	0.14	0.02	2.96	0.4	1.12	1.22
P	0.37	0.30	0.15	1.39	0.42	1.00	1.04
Mg	0.19	0.11	0.05	1.00	0.16	0.74	0.66
K	3.94	0.41	0.25	1.30	3.37	0.91	1.05
Na	0.01	0.02	0.01	2.81	0.01	0.58	0.70

¹Protein/mineral pellet.²NDF-IP = NDF insoluble CP.³IVDMD = In vitro DM digestibility.⁴Calculated based on NRC (1989).

ent compositions of total diets (Table 3) were similar for all nutrients.

The in situ degradation of DM, NSC, and CP of CC and SFC are shown in Table 4. Soluble fraction of DM did not differ between CC and SFC (9.1%; $P > 0.05$). Previous studies (Lykos et al., 1997; Bargo et al., 1998) indicated that SFC had a higher soluble fraction of DM. The current trial evaluated feeds ground through a 1-

mm screen, while those previous studies evaluated feeds in their commercial form, which may explain the differences. The potentially degradable fraction of DM was higher for CC than SFC (93.5 vs. 78.7%; $P < 0.05$); however, the SFC had a higher rate of DM degradation (4.2 vs. 10.6% $P < 0.05$). These results are in agreement with other research (Lykos and Varga, 1995; Bargo et al., 1998). Neither soluble fraction (13.5%) nor the po-

Table 3. Estimated nutrient composition of total diets¹ (experiments 1 and 2).

Item	Experiment 1		Experiment 2	
	CC	SFC	GC	NFF
			% DM	
OM	92.4	92.7	91.0	90.8
CP	19.4	19.0	17.0	16.9
Soluble CP, % CP	25.9	25.1	24.6	24.9
Degradable CP, % CP	64.5	62.4	49.9	50.6
NDF	37.3	36.3	36.9	42.9
ADF	20.9	20.7	19.5	23.9
NSC	27.2	29.0	35.1	27.9
Ether extract	4.0	3.6	3.1	3.1
IVDMD ²	72.2	72.8	72.5	70.3
NE _L , ³ Mcal/kg	1.68	1.73	1.73	1.71
Ca	0.67	0.64	0.69	0.73
P	0.46	0.43	0.65	0.67
Mg	0.26	0.25	0.39	0.36
K	2.90	2.83	2.39	2.44
Na	0.32	0.32	0.24	0.29

¹Estimated using the average chemical composition of pasture and supplements, and weighting them according to estimated DMI (Table 5).²IVDMD = In vitro DM digestibility.³Calculated based on NRC (1989).

Table 4. In situ degradation of cracked-corn (CC), steam-flaked corn (SFC), ground corn (GC), and nonforage fiber (NFF) supplements.

Item	Experiment 1				Experiment 2			
	CC	SFC	SEM	P<	GC	NFF	SEM	P<
DM								
Soluble fraction, %	9.8	8.4	1.17	0.48	21.6	21.1	0.37	0.49
Potentially degradable fraction, %	93.5	78.7	0.77	0.03	79.5	74.8	1.90	0.22
Degradation rate, %/h	4.2	10.6	0.7	0.01	4.9	5.6	0.6	0.47
Effective degradability, ¹ %	48.5	58.6	3.27	0.16	57.1	57.1	2.17	0.98
NSC								
Soluble degradable fraction, %	14.0	13.0	2.35	0.76	21.1	29.4	0.53	0.01
Potentially degradable fraction, %	93.8	85.6	2.76	0.17	87.5	75.5	0.83	0.01
Degradation rate, %/h	5.2	10.3	0.9	0.05	5.8	6.7	0.2	0.05
Effective degradability, ¹ %	57.3	66.8	4.08	0.24	64.2	69.6	0.43	0.01
CP								
Soluble fraction, %	12.1	11.9	2.67	0.98	20.7	21.6	1.33	0.69
Potentially degradable fraction, %	66.0	83.2	8.10	0.27	87.7	84.2	3.17	0.87
Degradation rate, %/h	3.2	1.3	0.1	0.02	2.7	3.6	1.3	0.69
Effective degradability, ¹ %	34.1	23.8	3.76	0.19	47.8	48.9	4.03	0.86

¹Assuming passage of 6%/h (Lykos and Varga, 1995).

tentially degradable fraction (89.7%) of NSC differed between CC and SFC ($P > 0.05$). Lykos and Varga (1995) observed a higher soluble fraction with lower potential degradable fraction of NSC for SFC. Differences may have been due to difference in physical form of corn evaluated. Steam-flaked corn had a higher rate of degradation of NSC (10.3 vs. 5.2%/h; $P < 0.05$) and numerically higher values of effective ruminal degradability of NSC (66.8 vs. 57.3%), in agreement with Lykos and Varga (1995). The soluble fraction and potentially degradable fraction of CP were similar between CC and SFC (12.0%; $P > 0.05$). However, SFC showed a lower degradation rate of CP (1.3 vs. 3.2%/h; $P < 0.05$), which contributed to a numerically lower effective ruminal degradability of CP (23.8 vs. 34.1%). This was likely due to heating during the processing of SFC.

Dry matter intake data are shown in Table 5. Supplement DMI did not differ between treatments and averaged 7.2 kg/d ($P > 0.05$). Pasture (15.1 kg/d) and total DMI (22.3 kg/d) did not differ for cows fed CC or SFC ($P > 0.05$). These results agree with the study of Bargo et al. (1998) that found no differences in DMI when

feeding SFC and CC to cows grazing alfalfa. Reis and Combs (2000) also observed no differences in pasture or total DMI of dairy cows grazing a legume/grass pasture and supplemented with dry corn or steam-rolled corn. Studies feeding SFC and dry processed corn on TMR also indicated no differences in DMI (Joy et al., 1997; Dann et al., 1999). Yu et al. (1998) found increased DMI for SFC compared to finely GC, but no difference when compared to coarsely ground or steam-rolled corn. Variation in reported DMI may be due to differences in rumen fermentation with increased starch digestion. Fiber digestion may be reduced due to increased starch digestion and decreased rumen pH (Sutton et al., 1987), and therefore reduce DMI. However, neither Bargo et al. (1998) nor Reis and Combs (2000) reported differences in rumen pH with dry corn or steam processed corn supplementation. Bargo et al. (2003) reviewed the literature on supplementation to high producing dairy cows on pasture and concluded that replacement of dry cow by processed corn did not affect DMI.

Production of milk (24.3 kg/d) and 3.5% FCM (24.9 kg/d) did not differ between cows fed CC or SFC (Table

Table 5. Dry matter and nutrient intake of pasture and supplements (experiments 1 and 2).

Item	Experiment 1				Experiment 2			
	CC	SFC	SEM	P<	GC	NFF	SEM	P<
Number of cows	8	8			13	13		
Pasture DMI, kg/d	15.5	14.6	0.54	0.30	12.1	12.0	0.36	0.84
Supplement DMI, kg/d	7.2	7.2	0.25	0.99	8.2	8.2	0.02	0.91
Total DMI, kg/d	22.7	21.8	0.67	0.41	20.3	20.2	0.36	0.82
Total DMI, % BW	3.43	3.30	...	...	3.19	3.20	...	...
NE _L intake, Mcal/d ¹	38.1	37.7	1.13	0.81	34.8	34.3	0.60	0.50

¹Estimated based on NRC (1989).

Table 6. Milk production and composition, BW, BCS, and blood and urine metabolites (experiments 1 and 2).

Item	Experiment 1				Experiment 2			
	CC	SFC	SEM	P<	GC	NFF	SEM	P<
Number of cows	14	14			28	28		
Milk production and composition								
Milk kg/d	24.3	24.3	1.11	0.96	27.6	27.4	0.58	0.56
3.5% FCM, kg/d	25.2	24.5	1.03	0.65	27.6	27.8	0.72	0.68
Milk fat, %	3.73	3.58	0.10	0.28	3.53	3.63	0.04	0.08
Milk fat, kg/d	0.90	0.86	0.04	0.47	1.05	1.08	0.02	0.24
Milk protein, %	3.26	3.34	0.03	0.27	3.23	3.19	0.01	0.04
Milk protein, kg/d	0.78	0.80	0.05	0.63	0.96	0.95	0.01	0.21
MUN ¹ , mg/dl	16.3	14.8	0.62	0.10	14.9	15.4	0.13	0.02
BW and body condition								
BW, kg	662	661	18.2	0.96	617	626	5.9	0.29
BW change, kg/d	0.302	0.550	0.235	0.46	0.268	0.143	0.209	0.37
Body condition score ²	2.9	2.8	0.09	0.67	2.9	2.9	0.02	0.89
BCS change, units/d	-0.005	-0.002	0.001	0.14	-0.001	-0.001	0.001	0.70
Plasma metabolites								
Glucose, mg/dl	69.2	68.5	1.06	0.65	70.0	68.7	0.27	0.45
NEFA, meq/L	150	135	19.3	0.60	141	166	7.8	0.02
PUN ³ , mg/dl	13.7	12.5	0.32	0.02	12.9	13.3	0.13	0.13
Urine metabolites								
Allantoin (A), mg/L	...	...	...	...	1735	1654	77	0.47
Creatinine (C), mg/L	...	...	...	...	505	546	29	0.33
A:C ratio	...	...	...	...	3.65	3.47	0.24	0.60

¹MUN = Milk urea N.²Five-point scale (1 = thin and 5 = fat).³PUN = Plasma urea N.

6). Bargo et al. (1998) found no difference in milk production for grazing cows. High producing dairy cows on pasture had similar milk production with dry corn or steam-rolled corn (Reis and Combs, 2000). Yu et al. (1998) observed increased milk production by cows fed SFC of 0.36 kg/L density compared with SFC of 0.31 kg/L density, finely ground corn, steam-rolled corn, and dry rolled corn in a TMR. Dann et al. (1999) also indicated increased milk production in early-lactation cows when feeding SFC versus CC in a TMR. A recent review on supplementation for high producing dairy cows on pasture (Bargo et al., 2003) indicated that similar milk production can be expected when dry corn is replaced by processed corn. In the current study, estimated NE_L intake did not differ between treatments (37.9 Mcal/d; $P > 0.05$; Table 5). Cows were over 200 DIM and NE_L intake likely exceeded requirements for the observed milk production. However, NE_L estimates for SFC may be low (Theurer et al., 1999), and energy may have been directed toward body reserves. Changes in body reserves are difficult to detect in a 6-wk period. Milk fat composition (3.66%) and yield (0.88 kg/d) were not affected by treatment ($P > 0.05$; Table 6). This agrees with other studies (Bargo et al., 1998; Reis and Combs, 2000), which reported no effect on milk fat content when feeding steam-processed grains. Other researchers have indicated decreased milk fat content when feeding

SFC (Dann et al., 1999; Yu et al., 1998). Milk protein composition (3.30%) and yield (0.79 kg/d) were not affected by treatment ($P > 0.05$), but were numerically higher with SFC. Supplementation with steam-rolled corn to high producing dairy cows on pasture tended to increase milk protein content compared to dry corn (Reis and Combs, 2000). When feeding SFC on a TMR, some studies (Joy et al., 1997; Yu et al., 1998) have shown no increase in protein content, while others (Chen et al., 1994; Knowlton et al., 1996) have shown higher protein content when compared to dry corn. Milk urea N tended to be lower with SFC (14.8 vs. 16.3 mg/dl; $P < 0.10$), suggesting an improvement in N utilization. Utilizations of N may have been increased with SFC by a greater ruminal N captured because of a higher rumen available NSC and by a lower ruminal N produced because of a lower RDP. This is consistent with other studies (Dann et al., 1999; Reis and Combs, 2000) feeding processed grains. A summary of literature with high producing dairy cows on pasture reported slight reduction in milk fat content and increase in milk protein content when dry corn is replaced by processed corn (Bargo et al., 2003).

Body weight averaged 662 kg and was not different between treatments at the start of the trial. Body weight increased 18 kg for both treatments for the 6-wk period (Table 6), with no differences in BW change

between treatments. Body condition score averaged 2.85 at the start of the experiment and decreased slightly over the 6-wk period. Treatments did not affect change in BCS. Plasma and NEFA concentrations did not differ when cows were fed CC or SFC (Table 6). Plasma urea N was decreased (12.5 vs. 13.7 mg/dl; $P < 0.02$) for cows fed SFC, in agreement with MUN. Other studies have also reported observed that feeding steam-flaked grain to cows on pasture decreased plasma urea N (Bargo et al., 1998).

Experiment 2

In experiment 2, herbage mass averaged 2810 kg of DM/ha for both periods. The GC and the NFF-based supplements were similar in CP, ether extract, and IVDMD (Table 2). The NFF-based supplement was higher in NDF and lower in NSC than the GC-based supplement. Nutrient composition of pasture (Table 2) was below the quality typically observed in similar pastures (Muller and Fales, 1998). Spring weather conditions were not ideal for consistent pasture growth during this trial. Rainfall was high before the experiment, but at the start of the first experimental period, drought conditions caused grass to mature quickly. Subsequent lack of rainfall persisted through the rest of the trial resulting in slow pasture growth, and the need to harvest pasture for an 18-d period. Total diet composition (Table 3) were similar in CP, ether extract, degradable protein, and IVDMD. The NFF diet was higher in NDF (42.9 vs. 36.9%) and lower in NSC (27.9 vs. 36.1%) compared with the GC diet.

In situ degradation of DM, NSC, and CP of the GC and the NFF-based supplements are shown in Table 4. Parameters of DM degradation did not differ significantly between the GC and the NFF-based supplements ($P > 0.05$). The NFF-based supplement had a higher soluble fraction (29.4 vs. 21.1; $P < 0.05$) and degradation rate (6.7 vs. 5.8%/h; $P < 0.05$) of NSC, resulting in a higher effective degradability of NSC (69.6 vs. 64.2%; $P < 0.05$) compared to the GC-based supplement. This may be due to higher pectin content in the NFF-based supplement. The values for the different fractions for the GC-based supplement were similar to values found by Kolver et al. (1998). In situ CP degradation did not differ for the GC and NFF-based supplements ($P > 0.05$). Both supplements had low degradation rates for CP (3.2%/h), and effective degradability of CP was lower than 50%, which may be attributed to the use of corn and distillers in both supplements.

Dry matter intake of pasture and supplement are reported in Table 5. Ground corn and NFF-based supplements DMI averaged 8.2 kg/d with no refusals. Pasture (12.1 kg/d) and total (20.3 kg/d) DMI did not differ

between treatments (Table 5). These results are consistent with previous studies (Valk et al., 1990; Spörndly, 1991), which showed no differences in DMI between fiber-based and starch-based supplements. Other studies found increased pasture and total DMI with fiber-based supplements compared to starch-based supplements (Meijs, 1986; Kibon and Holmes, 1987; Sayers, 1999). Meijs (1986) postulated that feeding a fermentable starch supplement in conjunction with highly degradable fresh forage reduced rumen pH and decreased herbage digestion (Arriaga-Jordan and Holmes, 1986), resulting in a longer rumen retention of feed, thus limiting DMI. Meijs (1986) suggested a higher pH is maintained when starch-based supplements are replaced with fiber-based supplements, which may result in higher DMI.

Forage quality and starch composition can affect rumen pH and may explain differences in pasture DMI among experiments. Cows fed perennial ryegrass pasture and fiber-based supplements had increased pasture DMI compared with cows fed a starch-based supplement (Meijs, 1986; Kibon and Holmes, 1987); however, cows fed less fermentable forage with the addition of hay had no differences in DMI (Spörndly, 1991). Meijs (1986), Kibon and Holmes (1987), and Stakelum and Dillon (1988) used barley and cassava as starch sources. Corn is not as degradable in the rumen as barley (Herrera-Saldana et al., 1990), and may not be as detrimental to rumen pH and herbage digestibility. Valk et al. (1990) indicated no benefits in DMI when comparing fiber to corn-based supplements because of the slower ruminal degradation of corn compared to other starch sources such as barley.

Milk production did not differ between treatments (27.5 kg/d; $P > 0.05$; Table 6), which could be attributed to the lack of positive effects of NFF-based supplements with medium quality pastures (>50% NDF, <65% IVDMD). This may have resulted in a high ruminal pH, therefore it may not expected any advantages of NFF over GC. Replacing starch with fiber-based supplements has increased milk production in some studies using high quality pastures such as ryegrass (Meijs, 1986; Sayers, 1999). Other studies have indicated no effect on milk production (Garnsworthy, 1990; Valk et al., 1990; Spörndly, 1991), or a decreased milk production (Valk et al., 1990). Valk et al. (1990) attributed decreased milk production with fiber-based supplements to a lower energy intake compared with the starch-based supplements. In a second experiment, Valk et al. (1990) fed a corn and a fiber-based supplement to a similar energy intake and observed no differences in milk yield. Studies have reported DMI responses to fiber-based supplements with no milk response (Kibon and Holmes, 1987; Stakelum and Dillon,

1988). Fiber sources such as beet pulp are lower in energy content than corn or barley and therefore increased DMI may not result in higher energy intake. The supplements in the current trial were formulated to be similar in energy content, therefore similar DMI resulted in a similar energy intake. Another possible reason for differences between studies could be the source of NFF because different sources differ in energy and pectin content, and rate of degradation (NRC, 1989). In a review on supplementation to high producing dairy cows on pasture, Bargo et al. (2003) found that milk production was slightly reduced when fiber-based supplements replaced starch-based supplements, but with a large range of variation among studies.

Milk fat percentage tended to increase (3.63 vs. 3.53%; $P < 0.08$) with NFF-based supplements with no change in milk fat yield (1.07 kg/d; $P > 0.05$). Sutton et al. (1987) found increased fat yield with fiber versus starch-based supplements, and attributed this to an increased production of ruminal propionate with starch-based supplements and a subsequent depression in milk fat. Other studies have indicated no changes in milk fat content or yield when starch was replaced by fiber-based supplements (Kibon and Holmes, 1987; Garnsworthy, 1990; Spörndly, 1991). Milk protein percentage was increased (3.23 vs. 3.19%; $P < 0.04$) with GC-based supplement (Table 6). The use of a GC-based concentrate may have provided more starch in the rumen, resulting in higher production of propionate, and therefore increasing milk protein content. Replacing starch by NFF-based supplements has not previously resulted in changes in milk protein percentage (Meijs, 1986; Kibon and Holmes, 1987; Valk et al., 1990). Cows fed the GC-based supplements had a lower MUN (14.9 vs. 15.4 mg/dl; $P < 0.02$) content (Table 6). This suggests improved N utilization for cows fed the GC-based supplement. One of the few studies that have reported MUN for fiber and starch supplements on pasture indicated no difference in urea in milk (Schwarz et al., 1995). Bargo et al. (2003) reviewed the literature on supplementation for high producing dairy cows on pasture and concluded that most of the studies did not report changes in milk fat percentage and a small reduction in milk protein percentage when fiber replaced starch.

Body weight and BCS are reported in Table 6. Cows averaged 621 kg at the start of the trial, and it was not different between treatments ($P > 0.05$). Body weight gain was minimal and the overall change in BW was not different between treatments ($P > 0.05$). Body condition was not different at the start of the trial, and the change on BCS did not differ between treatments ($P > 0.05$).

Blood metabolites are also reported in Table 6. Plasma glucose did not differ between diets (69.3 mg/

dl; $P > 0.05$). Plasma urea N tended to be lower with the GC-based supplements (12.9 vs. 13.3 mg/dl; $P < 0.13$), which is consistent with the lower MUN. The higher concentrations of NEFA in cows fed the NFF-based supplement (166 vs. 144 $\mu\text{eq/L}$; $P < 0.05$) suggested that cows were mobilizing more adipose tissues, but BW and BCS data did not indicate this. The ratio of allantoin and creatinine did not differ between cows fed the GC or the NFF-based supplements (3.56; Table 6; $P > 0.05$). Allantoin measures were similar to those reported by Carruthers et al. (1997) for cows fed fresh forage. Bargo et al. (2002) found an allantoin:creatinine ratio of 3.35 for high producing dairy cows on pasture supplemented with a corn-based concentrate. However, it should be mentioned that the use of allantoin to estimate microbial protein on grazing cows has not been validated yet.

CONCLUSIONS

Feeding a more ruminally degradable carbohydrate such as SFC to lactating dairy cows grazing pasture did not affect DMI, milk production, or milk composition. However, SFC resulted in lower plasma and milk urea N, suggesting improved N utilization compared with CC when cows grazed a good quality pasture (<50% NDF, >65% IVDMD). Feeding NFF-based supplements instead of corn-based supplements had no effect on DMI, milk production, or milk composition of midlactation dairy cows grazing medium quality pasture (>50% NDF, <65% IVDMD), although a trend for higher milk fat percentage existed. Corn supplementation increased milk protein percentage and decreased urea N in milk, suggesting that cows fed corn-based supplements utilized N more efficiently than cows fed the NFF supplement. This also suggested that supplementation with starch-based concentrates may be more beneficial with medium quality pastures, while supplementation with fiber-based concentrates may be more beneficial with high quality pastures.

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