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Corn bran versus corn grain at 2 levels of forage: Intake, apparent digestibility, and production responses by lactating dairy cows

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ABSTRACT

The objective of this study was to determine the effect of substituting corn bran (CB) for dried ground corn grain (CG) in the nonforage portion of high-forage (HF) and low-forage (LF) diets. Twelve multiparous and 12 primiparous Holsteins were assigned to 4 diets using six 4 × 4 Latin squares with 3-wk periods. Forage was 64 or 38% of the total mixed ration (% of dry matter). On a dry matter basis, the HFCG diet had 20% CG, the LFCG diet had 39% CG, the HFCB diet had 19% CB, and the LFCB diet had 38% CB. Digestible organic matter intake (OMI) and milk energy yield were lower for CB compared with CG within forage level. Digestible OMI was greater (1.9 kg/d) for the LFCG compared with the HFCG treatment. When CB replaced forage (LFCB vs. HFCB), digestible OMI was not different but milk energy yield was greater with the LFCB diet. The LFCG diet supported the greatest milk, milk protein, and milk energy yield. Decreased concentration of milk protein and increased concentration of milk urea nitrogen when feeding CB compared with CG suggests that lack of fermentable energy in the CB diets may have limited rumen microbial protein synthesis. Total substitution of CG with CB in the nonforage portion did not support maximum milk production, even when forage was reduced at the same time (HFCG vs. LFCB). Predicted neutral detergent fiber (NDF) digestibility at 1 times maintenance, based on chemical analysis of the individual feeds, was 22 percentage units greater for CB than for the forage mix (68.9 vs. 46.9%). In vitro NDF digestibility (30 h) was 19.4 percentage units greater for CB than for the forage mix (68.9 vs. 49.5%). However, in vivo NDF digestibility of the diet when CB replaced forage (HFCB vs. LFCB) was similar (44.1 vs. 44.5%). Similarly, predicted total digestible nutrients at the production level of intake, based on chemical analysis, were greater for the CB treatments and lower for the CG treatments than those observed in vivo.
Key words: corn bran, corn grain, fiber source

INTRODUCTION

Feed costs are the largest part of the total production costs in dairy cattle operations. Using alternative, potentially less expensive feed sources that do not negatively affect total production and other performance measures may increase profitability. Within the alternative feed sources, attention should be given to coproducts from the corn ethanol industry because in 2013, the corn ethanol industry produced 84,088 t of livestock feed (RFA, 2014).

Corn ethanol is produced by the fermentation of corn starch. Different ethanol production processes produce a variety of coproducts. These coproducts contain mostly protein, fiber, and fat (RFA, 2008). The fiber is derived from the corn pericarp or corn bran (**CB**), the outer coating of the corn kernel (Watson, 2003). However, compared with corn grain (**CG**), grain milling or fermentation coproducts have a lower NFC and starch and higher NDF, CP, and ether extract (**EE**) content. Currently, the 2 major coproducts are corn gluten feed (35.5% NDF and 34.0% NFC; NRC, 2001) from wet milling, and distillers grains with solubles (38.8% NDF and 24.6% NFC; NRC, 2001) from the conventional dry grind process. Both wet corn gluten feed and distillers grains with solubles have been shown to successfully substitute for part of the forage mix or concentrate portion, or both, in dairy cow rations without detrimental effects on cow performance (Schingoethe et al., 2009; Ranathunga et al., 2010). Also, Janicek et al. (2007) observed no negative effect on lactating dairy cow performance when CB increased from 10 to 25% dietary DM, replacing forage. However, the feed denoted as CB contained relatively low NDF (30.4%) and high NFC (45%). Thus, the role of NDF in these coproducts cannot be evaluated from these studies because the NDF content of these coproducts was <40% of DM. Pure CB comprises predominantly NDF, as it comes from the pericarp and tip cap of the CG, which contain 90 and 95% NDF (% of DM), respectively (Watson, 2003).

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The objectives of the present study were to estimate the nutritional value of relatively pure CB compared with CG in the nonforage portion of the diet at 2 levels of forage [i.e., high forage (**HF**) and low forage (**LF**)], and thereby to evaluate the value of CB fiber relative to whole corn grain. These treatment arrangements also allowed comparison of CB replacing forage (HFCB vs. LFCB), and CB replacing a mixture of CG and forage (LFCB vs. HFCG). The effects of these treatments on performance, intake, and apparent total-tract digestibility of the diets were evaluated.

MATERIALS AND METHODS

Cows and Experimental Design

Twelve multiparous and 12 primiparous lactating Holstein cows, averaging 103 ± 14 (mean ± SD) DIM at the beginning of the experiment were used in a 4 × 4 Latin square design with 21-d periods. The 6 Latin squares were arranged as a randomized complete block in which cows were blocked by production (low, medium, and high) within parity (primiparous and multiparous) before assignment to a square. The 3 production levels were determined by using 305-d projected milk yield (DairyCOMP 305; Valley Agricultural Software, Tulare, CA). Within parity, 3 Latin squares with different treatment sequence patterns were used to balance for single-period carryover, with the same set of 3 squares used for both parity groups. However, production groups were randomized to squares and cows were randomized within squares. The 305-d projected milk yield for high, medium, and low cows was 25,346, 21,853, and 19,854 kg, respectively. All cows were injected with bST (500 mg of Polisac; Monsanto Co., St. Louis, MO) at 14-d intervals.

Cows were housed in individual tie-stalls and had free access to water throughout the experiment. Cows were milked twice daily at 1535 and 0435 h and milk weights were recorded. Care and handling of the animals was conducted under protocols approved by the University of Wisconsin-Madison College of Agricultural and Life Sciences Institutional Animal Care and Use Committee.

Diets

Four diets with 2 different forage levels (HF or LF), supplemented with ground dried CG or CB in the nonforage portion of the diet were offered as TMR to the cows: HFCG, HFCB, LFCG, and LFCB (Table 1). The LF diet concentrate contained (DM basis) 55.9% CG or 53.9% CB, and the HF diet concentrate contained 63.8% CG or 61.5% CB. A larger absolute substitution of CB for CG in the LF diets was made due to a larger proportion of nonforage mix in the LF diets compared with the HF diets. The forage portion was 55% corn silage and 45% alfalfa silage for all diets. Proportions of feeds within the nonforage portion of the diet had to be altered between HF and LF diets to meet the requirements of the lactating cows. For the HFCG, LFCG, HFCB, and LFCB, the cottonseed proportion in the nonforage portion of the diet was similar (10.3, 9.8, 11.9, and 11.3%, respectively) as was distillers grains with solubles (2.5, 2.5, 2.9, and 2.9%, respectively). The soybean meal and blood meal portions of the nonforage portion of the diet were used to create rations similar in CP, RUP, and RDP content, based on evaluations made with the NRC (2001) model.

All cows were fed once daily at 0900 h. Animals were fed ad libitum and intakes were adjusted daily to achieve 10% refused feed. Average dietary chemical compositions are reported in Table 2. Diet chemical compositions were calculated based on diet feed ingredient composition and chemical analysis of individual feed samples for all components but RUP, RDP, NE_L, and diet mineral composition. Rumen-undegradable protein, RDP, and NE_L contents were predicted using the NRC (2001) and observed intakes. Diet mineral composition was analyzed from 1 TMR composited for each diet across all 4 periods.

External Markers

The external digestibility marker used was Yb (Prigge et al., 1981). Ytterbium was dosed over the last 10 d of each period via a Yb-marked soybean meal premix that was mixed into the TMR. A purchased $YbCl_3$ solution analyzed to contain 331 g of Yb/L by the supplier (Rhodia Inc., Phoenix, AZ) was diluted with distilled H_2O to prepare Yb solutions containing 62 g of Yb/L. Each period, Yb-marked soybean meal was prepared by spraying a total of 6 L of Yb solution, using a hand-held sprayer (1 gal., model 71967; Ace Hardware Corp., Oak Brook, IL), on 170 kg (as fed) of soybean meal while being mixed in a Leeson feed mixer (model C6C17FB2F; Leeson Electric Corp., Grafton, WI). Ytterbium was delivered to the cows within the TMR by replacing part of the unmarked soybean meal (87.9% DM) with an equal weight (as fed) of the Yb-marked soybean meal (86.5% DM) in the TMR mixer. On the first day of marker dosing, approximately 1.5 g of Yb/cow was provided and the following days approximately 1.0 g Yb/cow was provided. The concentration of Yb was analyzed in a composite sample of each TMR for each period and in the composited feed refusals from each individual cow for each period. Intake of Yb of each individual cow was calculated by the difference of Yb offered and refused by each individual cow. Dur-

Table 1. Ingredient composition of the diets

Item, % of DM	Treatment[1]			
	HFCG	HFCB	LFCG	LFCB
Forage mix				
Corn silage	35.6	35.6	21.3	21.3
Alfalfa silage	28.6	28.6	17.1	17.1
Nonforage mix				
Corn grain (ground)	20.0	—	39.3	—
Corn bran	—	19.3	—	37.9
Whole cottonseed	3.7	3.5	7.3	7.0
Distillers dried grains with solubles	0.9	0.9	1.8	1.8
Soybean meal	7.8	8.0	10.7	11.1
Blood meal	0.9	1.6	—	1.4
Vitamins and minerals[2]	2.5	2.5	2.5	2.5

[1]HFCG = high-forage corn grain; HFCB = high-forage corn bran; LFCG = low-forage corn grain; LFCB = low-forage corn bran.

[2]Commercial premix that provided a guaranteed minimum concentration of (on an as-fed basis) 14.7% Ca, 10.3% salt, 13.9% Na, 4.5% Mg, 0.4% K, 0.9% S, 14 mg of Se/kg, 282,192 IU of vitamin A/kg, 55,116 IU of vitamin D/kg, and 1,334 IU of vitamin E/kg.

ing the last period, the second day of Yb dosing was unintentionally omitted for all cows.

Sampling and Sample Preparation

Samples of all individual feedstuffs and forages were collected on d 15, 17, 19, and 21 of each period. All samples were frozen at −20°C. Dietary nonforage samples were dried at 60°C for 48 h, composited on an equal-weight basis by period, and ground to pass through a 1-mm screen of a Wiley mill (Arthur H. Thomas Co., Philadelphia, PA). Total mixed ration samples and individual cow refusal feed samples were collected daily over the last 5 d of each period and frozen at −20°C. Frozen forage and TMR samples were thawed, subsampled for particle size analysis, and composited by period. Feed refusal samples were composited by period and cow according to as-fed daily refused feed weights. Total mixed ration composites and feed refusal composites were dried at 60°C for 48 h and ground to pass the 1-mm screen of a Wiley mill (Arthur H. Thomas Co.). Ground samples were analyzed for analytical DM and Yb concentration. Also, dried ground TMR of each treatment was composited over the whole trial and analyzed for dietary mineral composition.

Eight fecal grab samples (each about 56 mL) were taken from each cow, at 9-h intervals over the last 4 d of each period, and immediately frozen at −20°C until composited by period. The period composite fecal sample of each cow was oven dried at 60°C to constant weight (72 h) and ground to pass the 1-mm screen of a Wiley mill (Arthur H. Thomas Co.).

Ten consecutive milk samples from each individual cow were collected the last 5 d of each period starting from d 17 at 1535 h. Samples were stored at 5°C for no more than 5 d and sent out for analysis to AgSource Milk Analysis Laboratory (Menomonie, WI).

Body weights of each cow were only measured on d 8 and 21 during period 4. Body weights were not recorded during periods 1, 2, or 3 or immediately before the trial.

Laboratory Analysis

Composited samples of each of the individual feedstuffs, silages, TMR, feed refusals, and fecal samples were analyzed at Dairyland Laboratories Inc. (Arcadia, WI). All samples were analyzed for analytical DM, CP, NDF, starch, EE, and ash. Nonforages and forages were also analyzed for neutral detergent-insoluble CP and acid detergent-insoluble CP. One composited TMR sample across all 4 periods for each diet was analyzed for analytical DM, Ca, P, Mg, K, S, Na, and Cl.

Analytical DM content was determined by drying at 105°C for 3 h (Shreve et al., 2006). Ash content was determined using the method of AOAC International (AOAC International, 2005; method 942.05). Crude protein content of feed samples was determined using a Leco combustion nitrogen analyzer (AOAC International, 2005; method 990.13). Neutral detergent fiber content was determined by gravimetric determination using heat-stable α-amylase and sodium sulfite (AOAC International, 2005; method 2002.04). Acid detergent fiber and lignin were analyzed according to AOAC International (2005; method 973.18). Acid detergent-insoluble CP was isolated according to AOAC International (2005; method 973.18) and analyzed by CP analysis (AOAC International, 2005; method 990.13). Neutral detergent-insoluble CP was isolated by gravimetric determination using heat-stable α-amylase and

Table 2. Chemical composition (% of DM, unless otherwise indicated) of the diets from calculations based on analyses of individual feedstuffs

Item[1]	Treatment[2]			
	HFCG	HFCB	LFCG	LFCB
DM, % as fed	42.2	42.2	53.2	53.1
OM	92.1	92.1	93.2	93.3
CP	17.0	17.3	16.8	17.4
RUP[3]	5.8	6.0	6.0	6.3
RDP[3]	11.2	11.4	10.8	11.1
EE	3.7	3.3	4.5	3.7
Ash	7.9	7.9	6.8	6.7
NDF	29.7	42.6	23.0	48.3
NDICP	1.1	1.4	1.0	1.6
FNDF	25.2	25.2	15.1	15.1
ADF	20.1	23.0	14.7	20.5
ADICP	0.8	0.9	0.7	0.8
Lignin	2.7	2.7	2.3	2.4
NFC[4]	41.7	28.9	48.9	23.9
Starch	25.6	14.9	34.0	12.9
NSNFC[5]	17.1	15.5	15.8	12.6
NE_L,[3] Mcal/kg of DM	1.55	1.52	1.59	1.54
Ca	0.96	1.01	0.78	0.89
P	0.33	0.32	0.39	0.31
Mg	0.31	0.28	0.30	0.26
K	1.46	1.56	1.29	1.14
S	0.19	0.17	0.18	0.17
Na	0.37	0.39	0.38	0.54
Cl	0.35	0.40	0.30	0.36

[1]EE = ether extract; NDICP = neutral detergent-insoluble CP; FNDF = forage NDF; ADICP = acid detergent-insoluble CP; NSNFC = nonstarch NFC.

[2]HFCG = high-forage corn grain; HFCB = high-forage corn bran; LFCG = low-forage corn grain; and LFCB = low-forage corn bran.

[3]Rumen-undegradable protein, RDP, and NE_L were predicted by the NRC (2001) model from the chemical composition at 25 kg of DMI/d for a 596-kg (BW) cow.

[4]NFC = 100 − (CP + NDF + EE + ash).

[5]NSNFC = NFC − starch.

sodium sulfite (AOAC International, 2005; method 2002.04) followed by CP analysis (AOAC International, 2005; method 990.13). Starch was analyzed using the enzymatic method described by Bach Knudsen (1997). It was hydrolyzed to glucose using heat-stable α-amylase and amyloglucosidase. The glucose was analyzed using a YSI 2700 Biochemistry Analyzer (YSI Inc., Yellow Springs, OH) with a dextrose enzyme membrane and autosampler. Ether extract was analyzed using the Soxtec System Application Note AN390 with acid hydrolysis followed by double extraction (AOAC International, 2005; method 920.39) using petroleum ether, which determines the total level of fat, including fat that is present as fecal soaps (Johnson and McClure, 1973). Calcium, P, Mg, K, S, and Na were analyzed using a microwave and furnace dry ash digestions according to AOAC International (2005; method 953.01). Chloride was analyzed by modified Volhard chloride estimation (Van Slyke, 1923; Wilson and Ball, 1928; Eisenman, 1929) using a Corning 926 Chloride Analyzer (Science Products, Corning Glass Works, Medfield, MA).

Thirty-hour in vitro NDF digestibility of forages, CG, CB, and 2 commercially available corn gluten feed samples were determined by the fermentation procedure described by Hall and Weimer (2007). Neutral detergent fiber values on an OM basis for the original samples and the 30-h in vitro fermentation samples were analyzed with sodium sulfite and heat-stable α-amylase (AOAC International, 2005; method 2002.04), with fermentation samples and media from each fermentation vessel transferred entirely to individual Berzelius beakers for the analysis. The NDF digestibility values (% of NDF) were calculated as [1 − (g of residual NDF after fermentation/g of sample NDF)] × 100.

The concentration of Yb in TMR, feed refusal, and fecal samples was analyzed by the modified method of AOAC International (2005; method 985.01) using inductively coupled plasma-optical emission spectroscopy (Vista-MPX Simultaneous ICP-OES; Varian Inc., Palo Alto, CA) at Analab Inc. (Fulton, IL) using wavelengths of 211.667, 222.447, 289.138, 328.937, and 369.419 nm to tabulate a median value.

Total mixed ration and forage particle size distribution were determined on an as-fed basis using both the Penn State Forage Particle Separator (The Pennsylvania State University, University Park) 4-box model (Heinrichs and Kononoff, 2002) and the Wisconsin Particle Size Separator (University of Wisconsin, Madison) in accordance with the American Society of Agricultural Engineers protocol (ANSI, 1998; ASAE Standard S424.1).

Milk samples were analyzed for fat, true protein, lactose, and MUN at AgSource Milk Analysis Laboratory by infrared analysis using a Foss MilkoScan FT6000 instrument (Foss Electric A/S, Hillerød, Denmark; AOAC International, 2005; method 972.16).

Calculation of Observed Intakes, Apparent Digestibilities, and Milk NE_L Requirements

Feed and feed component intakes were calculated by subtracting the amount of refusal from amount of feed offered (on DM basis). The observed intake of TDN at the production level of intake (**TDN_P**) was determined as follows:

$$\text{Observed } TDN_P \text{ intake (kg/d)} = \text{DOMI} + (\text{DFAI} \times 1.25), \quad [1]$$

where all values are expressed as kilograms per day, DOMI is apparently digestible OM intake, and DFAI is apparently digestible FA intake; DFAI was multiplied by 1.25 to account for the extra energy content of FA compared with the non-FA OM components (Volden, 2011).

Predicted TDN at 1 times maintenance (**$TDN_{1\times}$**) was calculated for each diet using the analyzed chemical composition of the feeds and NRC (2001) equations 2.4a to 2.4e and 2.5. The average DMI and predicted $TDN_{1\times}$ were used to estimate incremental intake above maintenance for each treatment, assuming TDN maintenance requirements of 35.2 g/kg of metabolic BW ($BW^{0.75}$; NRC, 1989), as follows:

$$\text{Incremental intake above maintenance} = [(TDN_{1\times} \times \text{DMI})/(0.0352 \times BW^{0.75})] - 1, \quad [2]$$

where DMI (kg/d) is treatment average observed DMI and BW is the average BW of all cows (696 kg). Incremental intake above maintenance was used to calculate the NRC (2001) discount factor [equation 2.9 of NRC (2001)] to convert predicted $TDN_{1\times}$ to predicted TDN_P.

Predicted digestible NDF for CB and the forage mix were determined by using NRC (2001) equation 2.4e and the analyzed chemical composition of the feeds. Milk NE_L requirement for each dietary treatment was determined according to NRC (2001) equation 2.15 using measured true milk protein, fat, and lactose percentages.

Statistical Analysis

For all models, blocking interaction terms were removed from models when $P > 0.25$. The Tukey-Kramer test was used for mean separation when the effect of treatment was $P < 0.05$. All analyses were performed using PROC MIXED of SAS (SAS Institute, 2004).

A single average value for daily milk yield, milk composition, apparent digestibility, and daily intake was obtained per cow per period. These data were analyzed using the following model:

$$Y_{ijklm} = \mu + a_i + b_j + c_k\,(a_i \times b_j) + p_1 + t_m + (a_i \times b_j) + (a_i \times p_1) + (a_i \times t_m) + (b_j \times t_m) + (b_j \times p_1) + (a_i \times b_j \times t_m) + e_{ijklm},$$

where Y_{ijklm} is the dependent variable; μ is the overall mean; a_i is the fixed effect of age of the cow (primiparous vs. multiparous); b_j is the fixed effect of production level (high, medium, or low); c_k is the random residual effect of cow, where k = 1 to 24; p_1 is the fixed effect of period, where l = 1 to 4; t_m is the fixed effect of treatment (HFCG, HFCB, LFCG, or LFCB); and e_{ijklm} is the random residual, assumed to be normally and independently distributed.

The interaction term treatment by parity by production was retained for NDF intake (kg/d; $P = 0.12$), CP digestibility (%; $P = 0.17$), and lactose yield (kg/d; $P = 0.21$). The interaction term period by production was retained for milk fat yield (kg/d; $P = 0.18$), starch intake (kg/d; $P = 0.24$), NFC intake (kg/d; $P = 0.22$), and digestible CP intake (kg/d; $P = 0.16$). When the interaction of parity by treatment or production level by treatment was significant ($P < 0.05$), treatment effects within each parity or production level were tested by using the SLICE statement in SAS.

RESULTS AND DISCUSSION

Diets

The chemical compositions of the CG, CB, corn silage, alfalfa silage, and forage mix used in the present study are presented in Table 3. Dietary treatments were designed to have similar CP, RUP, and RDP contents (Table 2) by slight variation of soybean meal and blood meal in the nonforage portion mixes between diets (Table 1). Although whole cottonseed and distillers dried grains with solubles were slightly different between diets, the nonforage portions of CB or CG to whole cottonseed and distillers dried grains with solubles remained similar across nonforage portions. Thus, observed differences between treatments were assumed to be related to differences in diet forage level, CB or CG in the nonforage portion, or both. This is supported by the major compositional difference between treatments in dietary carbohydrate fractions (starch, NFC, and NDF) and only marginal difference between treatments in CP, RUP, RDP, and EE. This choice of diets allowed the evaluation of CB substitution for CG on 2 levels of forage, CB substitution for forage (HFCB vs. LFCB), and CB substitution for a mixture of forage and CG (LFCB vs. HFCG).

The HF treatments and the LFCB treatment were within the NRC (2001) minimum recommendations for ADF, total and forage NDF, and maximum concentrations of NFC. The LFCG treatment was below the minimum recommended ADF content (14.8 vs. 21.0%), total NDF content (23.1 vs. 33.0%), and exceeded the maximum recommended dietary NFC content (48.8 vs. 36.0%) guidelines for diets containing forage NDF below 15% (NRC, 2001). The HF treatments had a numerically greater proportion of long particles than the LF treatments (Table 4).

Cow Performance

Feeding the LFCG diet resulted in the greatest milk yield, protein concentration, protein yield, and milk energy yield (Table 5). It also caused the lowest concentration of milk fat and MUN among the 4 diets, and resulted in lower milk fat yield than the HFCG diet. The LFCB diet resulted in lower milk fat and energy yields compared with HFCG, but no other milk component yields or concentrations differed significantly between these diets.

Although milk fat concentration was lowest when feeding the LFCG diet, the yield of milk fat was not different between the LFCG, HFCB, and LFCB treatments ($P = 0.12$). Thus, the low milk fat percentage resulting from the LFCG treatment relative to the 2 CB diets appears to be caused primarily by a dilution effect rather than depressed milk fat secretion. The greatest milk fat yield was observed with the HFCG treatment. This is in accordance with Pereira et al. (1999), who also observed greater milk fat yield in diets when increasing the forage-to-concentrate ratio (32.1 vs. 50.8% forage of TMR DM). However, this trend was not observed for the HFCB treatment.

Decreased milk protein content has been observed when dietary starch was reduced due to partial replacement of grains with soy hulls (Ipharraguerre and Clark, 2003; Gencoglu et al., 2010; Ferraretto et al., 2011). Thus, decreased milk protein yield when feeding CB diets may be due to lower starch intakes that could have led to lower amounts of starch escaping the rumen (Nocek and Tamminga, 1991; Rius et al., 2010) or lower rumen microbial yield (Oba and Allen, 2003), or both. The difference in starch could also explain the greater MUN concentration observed in both treatments containing CB because MUN was lowest for the highest

Table 3. Chemical composition (% of DM, unless otherwise indicated) of corn bran, corn grain, corn silage, alfalfa silage, and the forage mix

	Feedstuff[2]				
Item[1]	CG	CB	CS	AS	Forage mix
DM, % as fed	86.7	85.9	32.1	32.2	32.1
CP	8.9	6.9	7.3	23.0	14.3
EE	3.9	1.9	2.3	4.0	3.1
Ash	1.5	1.2	4.3	10.2	7.0
ADF	1.6	17.1	23.8	33.8	28.2
NDF	7.8	75.1	40.4	38.0	39.4
NDICP	0.7	2.5	0.7	2.0	1.3
ADF	1.6	17.1	23.8	33.8	28.2
ADICP	0.1	0.4	0.3	1.9	1.0
Lignin	0.4	0.7	0.8	6.9	3.5
NFC[3]	77.9	14.9	45.7	24.8	36.2
Starch	68.0	14.8	31.7	1.9	18.4
NSNFC[4]	10.6	2.6	14.7	22.9	19.1

[1]EE = ether extract; NDICP = neutral detergent-insoluble CP; ADICP = acid detergent-insoluble CP; NSNFC = nonstarch NFC.

[2]CG = corn grain; CB = corn bran; CS = corn silage; AS = alfalfa silage; forage mix = 55.5% corn silage and 45.5% alfalfa silage (% of DM).

[3]NFC = 100 − (CP + NDF + EE + ash).

[4]NSNFC = NFC − starch.

Table 4. Diet and forage particle size determined by using the Penn State Particle Separator (The Pennsylvania State University, University Park) and Wisconsin Particle Size Separator (University of Wisconsin, Madison)

Average recovered on screens, % as fed	Feedstuff[1]					
	HFCG	HFCB	LFCG	LFCB	CS	AS
Penn State Particle Separator						
Screen size						
19.1 mm	3.7	3.4	1.7	1.5	7.4	27.5
7.9 mm	50.9	46.3	35.9	31.6	65.2	46.4
1.3 mm	35.8	45.1	38.1	58.0	26.9	24.7
pan	9.7	5.2	24.3	8.8	0.5	1.3
Wisconsin Particle Size Separator						
Screen size[2]						
26.90 mm	3.4	3.4	2.8	3.4	5.4	10.1
18.00 mm	13.8	13.8	9.4	7.9	28.6	12.3
8.98 mm	32.8	29.8	25.3	23.7	34.1	39.0
5.61 mm	11.0	11.6	9.4	9.9	13.4	16.9
1.65 mm	21.6	29.3	21.1	39.5	14.2	16.1
pan	17.3	12.1	32	15.6	4.2	5.7
X_{gm},[3] mm	6.2	6.3	4.1	4.9	10.7	9.6

[1]HFCG = high-forage corn grain; HFCB = high-forage corn bran; LFCG = low-forage corn grain; LFCB = low-forage corn bran; CS = corn silage; AS = alfalfa silage.

[2]Screen sizes are diagonal distance within screen openings.

[3]Geometric mean length as calculated by the American Society of Agricultural Engineers protocol (ANSI, 1998; ASAE Standard S424.1).

starch diet and greatest for the lowest starch diet. Greater MUN concentration has also been associated with low-starch diets in other studies (Gencoglu et al., 2010; Ferraretto et al., 2011). Greater MUN concentration in low-starch diets could be due to lower capture of nitrogen by ruminal microbes, leading to a greater total ammonia pool. Hristov et al. (2005) showed greater ruminal ammonia concentrations in lactating dairy cows when comparing intraruminal dosing with NDF with dosing with starch. When CB nonforage mix replaced forage, a greater milk protein yield was observed without a difference in starch or digestible starch intake between the treatments.

An effect was detected of the interaction of treatment by parity on milk yield (P = 0.02) and milk lactose yield (P = 0.02). Additionally, an interaction of treatment by production level on milk fat yield (P < 0.01) and milk energy yield (P < 0.01; Table 5) was detected. Substitution of CG with CB led to qualitatively similar effects, regardless of production or parity group, but absolute treatment differences were more pronounced in multiparous and high-producing cows

Table 5. Milk production and milk composition LSM across parities and production levels

Item	Treatment[1]				SED[2]	Effect[3]		
	HFCG	HFCB	LFCG	LFCB		Trt	Trt × Par	Trt × Prod
Milk, kg/d	42.0[b]	38.7[c]	46.7[a]	40.5[bc]	0.7	<0.01	0.02	0.35
Milk composition								
Fat, %	4.03[a]	3.91[a]	3.47[b]	3.90[a]	0.09	<0.01	0.39	0.19
Protein, %	3.00[b]	2.91[c]	3.18[a]	2.95[bc]	0.03	<0.01	0.24	0.19
Lactose, %	4.94[b]	4.91[b]	5.00[a]	4.96[ab]	0.02	<0.01	0.13	0.93
NE_L,[4] Mcal/kg	0.739[a]	0.721[a]	0.698[b]	0.725[a]	0.008	<0.01	0.32	0.08
Milk component yield								
Fat, kg/d	1.70[a]	1.50[b]	1.61[b]	1.58[b]	0.04	<0.01	0.12	<0.01
Protein, kg/d	1.25[b]	1.12[c]	1.48[a]	1.19[b]	0.03	<0.01	0.42	0.10
Lactose, kg/d	2.07[b]	1.91[c]	2.33[a]	2.01[bc]	0.04	<0.01	0.02	0.64
NE_L,[4] Mcal/d	31.0[b]	27.8[d]	32.4[a]	29.3[c]	0.50	<0.01	0.15	<0.01
MUN, mg/dL	13.4[b]	17.5[a]	10.7[c]	18.4[a]	0.71	<0.01	0.74	0.46

[a–d]Least squares means within a row not sharing common superscript letters differ (P < 0.05).

[1]HFCG = high-forage corn grain; HFCB = high-forage corn bran; LFCG = low-forage corn grain; LFCB = low-forage corn bran.

[2]Standard error of the difference.

[3]Trt = main effect of treatment; Trt × Par = interaction between treatment and parity; Trt × Prod = interaction between treatment and production level.

[4]Calculated using observed milk fat, protein, and lactose content (NRC, 2001).

Table 6. Production, digestion, and intake LSM by parity for results where parity by treatment was significant

Item	Parity	Treatment[1]				SED
		HFCG	HFCB	LFCG	LFCB	
Milk, kg/d	Primiparous	37.5[b]	35.2[b]	41.0[a]	36.5[b]	0.98
	Multiparous	46.4[b]	42.2[c]	52.3[a]	44.5[bc]	0.98
Milk lactose, kg/d	Primiparous	1.87[b]	1.77[b]	2.07[a]	1.84[b]	0.05
	Multiparous	2.26[b]	2.05[c]	2.59[a]	2.17[bc]	0.05
NDF intake, kg/d	Primiparous	6.70[c]	9.30[b]	5.64[d]	11.21[a]	0.19
	Multiparous	7.97[c]	11.37[b]	6.65[d]	13.79[a]	0.19
Starch intake, kg/d	Primiparous	5.78[b]	3.21[c]	8.32[a]	2.95[c]	0.18
	Multiparous	6.89[b]	3.93[c]	9.76[a]	3.66[c]	0.18
Starch digestibility, %	Primiparous	96.5[ab]	97.4[a]	95.5[b]	97.2[a]	0.54
	Multiparous	97.1	96.5	97.1	96.6	0.54
Digestible NFC intake, kg/d	Primiparous	8.43[b]	5.66[c]	10.73[a]	4.95[c]	0.25
	Multiparous	10.06[b]	6.74[c]	12.64[a]	6.03[c]	0.25
Digestible starch intake, kg/d	Primiparous	5.00[b]	2.84[c]	6.82[a]	2.67[c]	0.26
	Multiparous	6.04[b]	3.45[c]	8.92[a]	3.22[c]	0.26

[a–d]Least squares means within a row not sharing common superscript letters differ ($P < 0.05$).

[1]HFCG = high-forage corn grain; HFCB = high-forage corn bran; LFCG = low-forage corn grain; LFCB = low-forage corn bran.

than in primiparous and low-producing cows (Tables 6 and 7).

Intakes, Digestibilities, Digestible Intakes, and Feed Efficiencies

Increasing forage level reduced DMI for CG- and CB-based diets (Table 8), but replacing CG with CB did not reduce DMI. Therefore reduced DMI was associated with increased NDF from forage, but not increased NDF from CB. Substituting CB for CG depressed digestibility of DM and OM, mostly due to the lowered starch content. Increased forage decreased DM and OM digestibility for the CG diets, but not for the CB diets. Therefore, intake of TDN_p was greatest with the LFCG diet due to high intake and digestibility, and was lowest on the HFCB diet due to reduced intake and digestibility compared with the LFCG diet. Intake

Table 7. Least squares means by production level for results where parity by treatment was significant

Item	Production level	Treatment[1]				SED
		HFCG	HFCB	LFCG	LFCB	
Milk fat, kg/d	High	2.04[a]	1.69[c]	1.99[ab]	1.80[bc]	0.07
	Medium	1.57	1.52	1.43	1.53	0.07
	Low	1.49	1.30	1.38	1.41	0.07
Milk NE_L,[2] Mcal of NE_L/d	High	36.2[a]	31.1[b]	38.5[a]	33.0[b]	0.84
	Medium	29.0	27.7	30.3	28.5	0.84
	Low	27.7[a]	24.6[b]	28.5[a]	26.3[ab]	0.84
NDF intake, kg/d	High	8.03[c]	11.44[b]	6.84[d]	13.94[a]	0.24
	Medium	7.02[c]	10.09[b]	5.95[d]	11.79[a]	0.24
	Low	6.95[c]	9.48[b]	5.66[d]	11.78[a]	0.24
Starch intake, kg/d	High	6.91[b]	3.95[c]	9.86[a]	3.65[c]	0.22
	Medium	6.08[b]	3.47[c]	8.94[a]	3.11[c]	0.22
	Low	6.02[b]	3.28[c]	8.31[a]	3.15[c]	0.22
Digestible NFC intake, kg/d	High	9.95[b]	6.83[c]	12.84[a]	6.05[c]	0.30
	Medium	8.88[b]	6.09[c]	11.61[a]	5.20[c]	0.30
	Low	8.92[b]	5.69[c]	10.60[a]	5.23[c]	0.30
Milk NE_L/DMI, Mcal/kg	High	1.34[a]	1.16[b]	1.30[a]	1.15[b]	0.05
	Medium	1.22	1.18	1.18	1.18	0.05
	Low	1.18[a]	1.10[ab]	1.16[a]	1.07[b]	0.05
Milk NE_L/TDN_PI,[3] Mcal/kg	High	2.12	1.93	1.97	1.93	0.06
	Medium	1.91[ab]	1.88[ab]	1.77[b]	1.99[a]	0.06
	Low	1.85	1.87	1.71	1.73	0.06

[a–d]Least squares means within a row not sharing common superscript letters differ ($P < 0.05$).

[1]HFCG = high-forage corn grain; HFCB = high-forage corn bran; LFCG = low-forage corn grain; LFCB = low-forage corn bran.

[2]Calculated using observed milk fat, protein, and lactose content (NRC, 2001).

[3]TDN_PI = intake of TDN at the production level of intake.

of TDN_p was almost identical for the HFCG and LFCB diets due to offsetting effects of decreased intake with HF and increased digestibility with CG.

A treatment by parity effect ($P < 0.05$) and a treatment by production effect ($P < 0.05$) were observed for NDF intake and starch intake (Table 8). Similar to production results, substitution of CG with CB had a qualitatively similar, but quantitatively greater, effect on NDF intake and starch intake for multiparous cows compared with first-parity cows (Table 6) and for high-producing cows compared with low-producing cows (Table 7). The same type of interactions occurred when comparing substitution of forage and CG with CB (HFCG vs. LFCB).

Organic matter digestibility was lower for treatments containing CB compared with treatments containing CG on the same forage level (Table 8). This most likely resulted from the higher NDF and lower NFC content of the CB treatments because NFC digestibility was more than double NDF digestibility (averages of 88.2 and 40.3%, respectively). Neutral detergent fiber digestibility was lower for the LFCG treatment compared with the other treatments. The reduced NDF digestibility of the LFCG treatment may be due to diet's abundance of highly digestible cornstarch inhibiting NDF digestibility. This finding is in accordance with Ferraretto et al. (2012), who also observed lower NDF digestibility of diets with similar forage concentration that were higher in starch. Therefore, it seems that the decreased NDF digestibility in LFCG was caused by an associative effect and not the source of the NDF. However, greater dietary NFC content and NFC digestibility more than compensated for the observed low NDF digestibility. No difference was observed for

Table 8. Intakes, apparent digestibility, and digestible nutrient intake LSM across parities and production levels

	Treatment[2]					Effect[4]		
Item[1]	HFCG	HFCB	LFCG	LFCB	SED[3]	Trt	Trt × Par	Trt × Prod
Intake, kg/d								
DM	24.8[bc]	24.3[c]	26.8[a]	25.8[ab]	0.4	<0.01	0.47	0.45
OM	22.9[b]	22.4[b]	24.9[a]	24.1[a]	0.4	<0.01	0.45	0.43
CP	4.24[b]	4.22[b]	4.48[a]	4.50[a]	0.07	<0.01	0.31	0.42
EE	0.92[b]	0.79[c]	1.20[a]	0.94[b]	0.02	<0.01	0.65	0.35
NDF	7.33[c]	10.34[b]	6.15[d]	12.50[a]	0.14	<0.01	<0.01	<0.01
NFC[5]	10.44[b]	7.09[c]	13.17[a]	6.25[d]	0.18	<0.01	0.12	0.06
Starch	6.34[b]	3.57[c]	9.04[a]	3.30[c]	0.12	<0.01	0.01	0.03
NSNFC[6]	4.10[a]	3.52[b]	4.14[a]	2.95[c]	0.06	<0.01	0.71	0.25
Digestibility, %								
DM	65.2[b]	60.7[c]	68.1[a]	58.7[c]	0.9	<0.01	0.47	0.45
OM	67.5[a]	62.6[b]	69.2[a]	60.6[b]	0.8	<0.01	0.12	0.244
TDN_P	63.9[b]	59.3[c]	67.0[a]	58.7[c]	0.8	<0.01	0.10	0.21
CP	64.0[b]	67.2[a]	66.5[a]	67.8[a]	0.8	<0.01	0.70	0.08
EE	56.9[b]	58.8[ab]	60.1[a]	62.8[ab]	2.1	<0.05	0.16	0.12
NDF	41.0[a]	44.1[a]	31.5[b]	44.5[a]	2.0	<0.01	0.53	0.09
NFC[5]	88.7	87.6	88.7	87.8	0.7	0.32	0.30	0.55
Starch	96.8	97.0	96.3	96.9	0.4	0.25	<0.01	0.56
NSNFC[6]	76.1[ab]	78.1[a]	72.2[b]	77.7[a]	1.7	<0.01	0.92	0.63
Digestible intake, kg/d								
OM	15.2[b]	13.8[c]	17.1[a]	14.5[bc]	0.3	<0.01	0.55	0.20
TDN_P	15.8[b]	14.8[c]	17.9[a]	15.7[b]	0.3	<0.01	0.91	0.13
CP	2.47[b]	2.60[ab]	2.51[ab]	2.78[a]	0.11	0.03	0.79	0.72
EE	0.59[b]	0.52[c]	0.80[a]	0.64[b]	0.02	<0.01	0.82	0.96
NDF	4.05[c]	5.94[b]	3.06[d]	7.28[a]	0.23	<0.01	0.10	0.27
NFC[5]	9.25[b]	6.20[c]	11.69[a]	5.49[d]	0.17	<0.01	<0.05	0.03
Starch	5.52[b]	3.14[c]	7.87[a]	2.95[c]	0.18	<0.01	<0.01	0.21
NSNFC[6]	3.11[a]	2.75[b]	2.98[a]	2.29[c]	0.08	<0.01	0.87	0.21
Milk NE_L/DMI, Mcal/kg	1.25[a]	1.15[b]	1.21[a]	1.14[b]	0.02	<0.01	0.06	0.01
Milk NE_L/TDN_PI, Mcal/kg	1.96[a]	1.89[ab]	1.82[b]	1.88[ab]	0.03	<0.01	0.64	<0.01

[a–d]Least squares means within a row not sharing common superscript letters differ ($P < 0.05$).

[1]EE = ether extract; NSNFC = nonstarch NFC; TDN_P = TDN at production level of intake; TDN_PI = TDN_P intake.

[2]HFCG = high-forage corn grain; HFCB = high-forage corn bran; LFCG = low-forage corn grain; LFCB = low-forage corn bran.

[3]Standard error of the difference.

[4]Trt = main effect of treatment; Trt × Par = interaction between treatment and parity; and Trt × Prod = interaction between treatment and production level.

[5]NFC = 100 − (CP + NDF + EE + ash).

[6]NSNFC = NFC − starch.

NFC digestibility or starch digestibility among treatments. Starch digestibility averaged 96.7% and NFC digestibility averaged 88.2%. Nonfibrous carbohydrate is composed of sugars, starches, organic acids, other reserve carbohydrates, and pectin. Thus, starch was subtracted from NFC to calculate dietary nonstarch NFC (**NSNFC**) concentration, NSNFC intake, NSNFC digestibility, and digestible NSNFC intake. Digestibility of NSNFC was different between treatments ($P <$ 0.01). It was greatest for the HFCB (78.1%) and lowest for the LFCG (72.2%) treatment. These results suggest that NFC digestibility cannot be considered constant or uniform, and the processing adjustment factors used in the NRC (2001) probably do not entirely explain variation in NFC digestibility.

An effect of treatment by parity was observed for starch digestibility ($P < 0.01$). In contrast to previous interactions, treatment differences were found for primiparous but not multiparous cows (Table 6).

The greatest digestible OM intake was observed for the LFCG treatment, followed by the HFCG and LFCB treatment, which did not differ from each other, and the lowest OM intake was observed for the HFCB treatment, which did not differ from the LFCB treatment (Table 8). Similarly, the greatest TDN_P intake and greatest digestible EE intake were observed for the LFCG treatment, followed by HFCG and LFCB treatment, which did not differ from each other, and the lowest TDN_P intake was observed for the HFCB treatment. Digestible CP intake differed between the HFCG and LFCB treatment but both treatments were not different from the HFCB and LFCG treatment. Digestible NDF intake had similar treatment mean separations as NDF intake because the LFCG treatment had the lowest NDF intake and lowest NDF digestibility, whereas NDF digestibility was similar among the remaining treatments. Similarly, digestible NFC and starch intake had similar treatment mean separations as NFC intake because the digestibilities of NFC and starch were not different among treatments. However, digestible NSNFC intake had similar treatment mean separations as NSNFC intake despite differences in NSNFC digestibility.

A treatment by parity effect was observed for digestible NFC intake ($P < 0.05$) and digestible starch intake ($P < 0.01$) and a treatment by production effect was observed for digestible NFC intake ($P =$ 0.03). However, separation mean rankings for all observations were similar between primiparous and multiparous cows and high-, medium-, and low-producing cows, but differences were greater on an absolute basis for multiparous compared with primiparous cows and high-producing cows compared with medium- and low-producing cows.

Milk NE_L/DMI, a measure of overall feed efficiency, was greater for the CG diets compared with the CB diets ($P = 0.01$), in agreement with the greater TDN_P content of these diets. Postabsorptive efficiency, calculated as milk NE_L/TDN_P intake, was lower for the LFCG diet compared with HFCG ($P = 0.01$); which explains the similar overall efficiency of use of HFCG DM compared with use of the LFCG DM, even though LFCG DM contained more TDN_P. These responses were qualitatively similar for the high- and low-production groups. For the medium-production group, overall efficiency was similar across treatments, and the LFCB diet had the highest postabsorptive efficiency, resulting in a significant treatment by production level for milk NE_L/DMI and milk NE_L/TDN_P intake ($P = 0.01$; Table 7). These calculations of feed efficiency do not consider changes in body energy stores, which may have varied across treatments.

Predicted and Observed TDN

The NRC-predicted $TDN_{1\times}$ were 72.3, 68.5, 77.6, and 70.2% and the NRC-predicted TDN_P using observed DMI were 63.8, 62.6, 64.0, and 62.8% for HFCG, HFCB, LFCG, and LFCB (NRC, 2001), respectively. Therefore, NRC-predicted TDN_P makes substitution of CB for CG and forage mix appear energetically similar. However, observed TDN_P were 63.9, 59.3, 67.0, and 58.7% for HFCG, HFCB, LFCG, and LFCB (Table 8), respectively. Observed TDN_P intake was greatest on the LFCG treatment, followed by HFCG and LFCB, which did not differ from each other, and the lowest TDN_P intake was observed for HFCB. Similarly, daily milk energy output was greatest for the LFCG treatment and lowest for the HFCB treatment (Table 5) but the HFCG compared with LFCB treatment led to a greater milk energy yield despite no difference in observed TDN_P intake between the 2 diets. However, cow performance seemed to be in accordance with observed TDN_P intakes. Thus, the NRC-predicted TDN_P of the HFCG diet overestimated TDN_P of HFCB and LFCB and underestimated the TDN_P of LFCG. The NRC $TDN_{1\times}$ prediction or the discount factor used for the conversion of $TDN_{1\times}$ to TDN_P, or both, could be the possible cause for the over- and underestimations.

Predicted, In Vitro, and In Vivo NDF Digestibilities

In vivo NDF digestibility was similar for the HFCB (59% of total diet NDF from the forage mix and 35% from CB) and LFCB diets (31% of total diet NDF from the forage mix and 58% of the NDF from CB). This indicates that NDF digestibility was similar for the forage and nonforage NDF sources, both approximating the 44% digestibility of total dietary NDF. Measured in vitro NDF digestibility (30 h) for the CB (68.9%) and the forage mix (49.5%) were similar to predicted NDF digestibility at 1× maintenance for the CB (68.9% digestibility) and the forage mix (46.9% digestibility) using our measured analysis and NRC prediction equations. The predicted and in vitro NDF digestibilities do not account for possible differences in passage rate of the CB and the forage mix. Our observed similar in vivo digestibilities for NDF in the HFCB and LFCB diets suggest that shorter rumen retention times of CB compared with the forage mix offset the increased fermentation rate of CB NDF compared with forage NDF.

The in vitro NDF digestibilities of 2 commercial corn gluten feeds we analyzed were 76.6 and 77.7%; thus, 7.7 and 8.8 percentage units greater than for the CB we fed. Therefore, our in vivo estimates of digestibility of CB NDF may underestimate the digestibility of NDF in corn gluten feed, a common source of CB NDF.

CONCLUSIONS

Direct substitution of CG with CB reduced yields of milk, milk energy, and milk protein for both HF and LF diets. Feeding CB also reduced the fat yield for the HF diets but not the LF diets. Even if forage was reduced simultaneously with CB substituting for CG (HFCG vs. LFCB), milk fat yield and energy yields were reduced, although yields of other milk components were not reduced significantly. Intake of TDN_P was similar for HFCG and LFCB; therefore, reduced intake of digestible energy does not explain this loss of milk energy yield. Diets in which CB only partially replaces CG and part of the forage may be preferable to the complete substitution of CG strategy used in this study.

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