Effects of feeding increasing levels of wet corn gluten feed on production and ruminal fermentation in lactating dairy cows¹

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ABSTRACT

An experiment was conducted to evaluate the effects of increasing dietary inclusion rates of wet corn gluten feed (WCGF; Sweet Bran; Cargill Inc., Blair, NE) on milk production and rumen parameters. Four primiparous and 4 multiparous ruminally cannulated Holstein cows averaging 90 ± 13 d in milk (mean $\pm$ SD) were randomly assigned to 1 of 4 sequences in a replicated 4×4 Latin square experiment with 28-d periods. Treatments were diets containing 0, 11, 23, and 34% WCGF on a dry matter basis; alfalfa hay, corn silage, corn grain, soybean meal, expeller soybean meal, and mineral supplements were varied to maintain similar nutrient concentrations across diets. Performance and measures of ruminal fermentation were monitored. Linear and quadratic effects of increasing WCGF inclusion rate were assessed using mixed-model analysis. Increasing dietary WCGF linearly increased dry matter intake (26.7, 25.9, 29.3, and 29.7 kg/d for 0, 11, 23, and 34% WCGF, respectively) and milk production (36.8, 37.0, 40.1, and 38.9 kg/d). Concentrations of milk components did not differ among treatments; however, protein and lactose yields increased linearly and fat yield tended to increase linearly when more WCGF was fed. This led to greater production of energy-corrected milk (38.2, 38.8, 41.7, and 40.4 kg/d) and solids-corrected milk (35.2, 35.7, 38.5, and 37.2 kg/d), but efficiency of production linearly decreased. Increased WCGF in the diet tended to linearly decrease ruminal pH (6.18, 6.12, 6.14, and 5.91), possibly because mean particle size was below typical recommendations for all diets, and diets with greater proportions of WCGF had a smaller mean particle size. Ruminal acetate concentration decreased linearly and propionate increased lin-

early as WCGF inclusion rate increased. Treatments had a quadratic effect on ammonia concentration, with greater concentrations for the 0 and 34% WCGF diets. In situ digestibility of soybean hulls showed a significant diet-by-time interaction, and increasing dietary levels of WCGF linearly decreased in situ neutral detergent fiber disappearance at 24 h. Change in body condition score increased linearly with increasing WCGF inclusion rate. Results indicate that adding WCGF to dairy rations can increase energy-corrected milk yield, and this increase appears to be driven, at least in part, by an increase in dry matter intake.

Key words: by-product, dairy cattle, wet corn gluten feed

INTRODUCTION

Increased demand for cereal grains has contributed to rising feed costs. Because many rations are formulated on a least-cost basis, researchers and producers are pressured to devise novel strategies to help control feed costs. Recently, focus has turned to the use of milling coproducts, particularly wet corn gluten feed (WCGF). Wet corn gluten feed is a rapidly digestible, nonforage source of fiber and protein (Firkins, 1997; Boddugari et al., 2001). Feeding WCGF to dairy cattle can be a low-cost method of providing energy and nutrients needed for milk production.

Defining the optimum amount of WCGF to incorporate into a TMR is complex because it interacts with other feed ingredients (Allen and Grant, 2000). The production response varies from case to case and is highly dependent on the nature of the other dietary ingredients (Armentano and Dentine, 1988; Schroeder, 2003; Kononoff et al., 2006). Formulating diets to complement the characteristics of WCGF rather than substituting WCGF for a single ingredient will increase the likelihood of optimizing its use in lactation diets (VanBaale et al., 2001). Physically effective NDF (peNDF) of WCGF was reported as 11% of NDF on the basis of rumination time and ruminal pH (Allen

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Table 1. Chemical composition of feeds used in experimental diets fed to lactating Holstein cows¹

Nutrient (% of DM $\pm$ SD)	WCGF	Corn silage	Alfalfa hay
DM (55°C, % as fed)	61.6 $\pm$ 0.4	39.2 $\pm$ 5.0	91.0 $\pm$ 1.0
DM (105°C, % as fed)	56.1 $\pm$ 0.9	35.7 $\pm$ 4.3	85.4 $\pm$ 1.0
CP	24.5 $\pm$ 0.4	8.8 $\pm$ 0.2	23.4 $\pm$ 0.6
NDF	35.3 $\pm$ 1.1	36.0 $\pm$ 1.1	34.5 $\pm$ 2.6
ADF	11.0 $\pm$ 0.9	22.5 $\pm$ 0.9	26.7 $\pm$ 1.8
Ether extract	2.3 $\pm$ 0.2	3.1 $\pm$ 0.1	1.4 $\pm$ 0.2
Starch	11.2 $\pm$ 0.5	36.8 $\pm$ 7.0	2.1 $\pm$ 1.0
Ash	5.8 $\pm$ 0.4	5.7 $\pm$ 1.4	9.8 $\pm$ 2.6

¹Samples collected on d 25 to 28 of all 4 periods. WCGF = wet corn gluten feed.

and Grant, 2000); therefore, sources of peNDF must be included when evaluating feedstuffs to complement WCGF. Rumination is stimulated when peNDF is provided, leading to longer chewing times, greater saliva production, and normal ruminal pH levels (Allen, 1997; Mertens, 1997). If the TMR does not provide adequate peNDF, rumen health may be compromised and milk fat depression can occur (Grant et al., 1990; Nocek, 1997).

Some investigators reported an increase in milk fat when incorporating WCGF into dairy cattle diets (Macleod et al., 1985; VanBaale et al., 2001); this is potentially related to the greater fiber content and lesser starch content of this feed. Feeding high levels of WCGF primarily in place of forage has been shown to increase ECM yield; this increase correlates with an increase in DMI (Kononoff et al., 2006).

Brouk et al. (2006) used known information about the feeding value of WCGF and associative effects to formulate 4 rations with linearly increasing amounts of WCGF. Increasing WCGF in the ration linearly increased milk and milk component production without increasing intake in a pen setting (Brouk et al., 2006). Such a response is suggestive of an increase in diet digestibility because milk yield per kilogram of DMI increased with greater WCGF. Also, adding WCGF to the diet could have increased the amount of RDP. Increased RDP may have led to increased ruminal fermentation, thus increasing ruminal digestion rate and microbial protein yield.

Generally, increased production responses to inclusion of nonforage fiber sources are correlated with cows consuming more DM (Armentano and Pereira, 1997). Because the findings of Brouk et al. (2006) were in contrast to the norm, our objective was to conduct a study in a tie-stall situation while feeding the same diets as Brouk et al. (2006). The primary aim of this study was to evaluate the effects of feeding increasing dietary concentrations of WCGF on production performance in lactating dairy cows. A secondary goal was to measure the effects of WCGF on the rumen environment and

ruminal fiber digestion of soybean hulls as a measure of associative effects in the rumen.

MATERIALS AND METHODS

Design and Treatments

Experimental procedures were approved by the Institutional Animal Care and Use Committee at Kansas State University. Four primiparous and 4 multiparous cannulated Holstein cows (90 $\pm$ 13 DIM; mean $\pm$ SD) from the Kansas State University Dairy Cattle Teaching and Research Center were assigned randomly to square and sequence within square in a replicated 4 $\times$ 4 Latin square design balanced for carryover effects. Animals were assigned randomly to 1 of 8 tie stalls. Treatment periods were 28 d, and the final 8 d were used for in situ work, data collection, and sample collection. At the beginning of the experiment, average BW and BCS of cows were 605 $\pm$ 27 kg and 2.76 $\pm$ 0.30, respectively.

Cows were offered 1 of 4 rations that differed in the amount of WCGF included. Targeted WCGF inclusion rates were 0, 12, 24, and 36% on a DM basis, but actual WCGF inclusion rates were 0, 11, 23, and 34% (DM basis). Chemical composition of the WCGF used in this study is shown in Table 1. Diets were formulated to meet or exceed NRC (2001) requirements for a Holstein cow producing 45 kg of milk/d; ingredient and nutrient analyses are shown in Table 2. Experimental diets were essentially the same as those used by Brouk et al. (2006). Diets were formulated to contain similar concentrations of CP, NDF, and NFC. As a consequence, diets containing more WCGF had less alfalfa, corn silage, corn grain, and soybean meal.

Data and Sample Collection

Throughout the experiment, cows were fed twice daily at 110% of previous daily intake. On d 25 to 28 of each period, the amount of feed offered and refused was recorded to determine DMI. Samples of all dietary

Table 2. Ingredient and nutrient compositions (% of DM) of diets containing increasing amounts of wet corn gluten feed (WCGF) fed to lactating Holstein cows

Item	Dietary WCGF (DM basis)			
	0%	11%	23%	34%
Ingredient				
WCGF ¹	0.0	11.4	23.2	33.6
Corn silage	25.2	25.5	22.1	18.4
Alfalfa	24.4	24.6	21.2	17.7
Cottonseed	6.1	6.2	6.2	6.1
Corn grain	23.5	19.9	17.3	14.6
Soybean meal	8.6	4.9	2.2	2.2
Molasses	0.4	0.4	0.4	0.4
Expeller soybean meal	3.3	3.7	4.0	3.6
Soybean hulls	5.0	—	—	—
Limestone	1.00	1.08	1.28	1.36
Magnesium oxide	0.26	0.24	0.21	0.17
Micronutrient premix ²	1.33	1.32	1.33	1.31
Nutrient				
DM (% as fed)	65.4	60.0	61.3	61.2
CP	19.3	18.8	19.1	20.1
RDP ³ (% of CP)	63.5	65.3	63.9	66.6
NDF	28.8	28.8	30.4	31.0
NDF supplied by forage	17.1	17.3	14.9	12.5
Starch	24.3	27.9	25.5	24.2
NFC ⁴	39.1	40.9	38.6	37.6
Ether extract	3.4	3.3	3.6	3.6
Ash	9.4	8.3	8.3	7.7

¹Sweet Bran; Cargill Inc., Blair, NE.

²Premix consists of 61.0% sodium bicarbonate, 27.3% trace mineral salt, 3.90% 4-Plex (Zinpro Corp., Eden Prairie, MN), 3.90% Se premix, 2.60% vitamin E premix, 1.30% vitamin A premix, and 0.21% vitamin D premix.

³Calculated using NRC (2001) equations.

⁴Calculated as DM – (CP + NDF + ether extract + ash).

ingredients were collected on d 25 to 28. Samples of the TMR and individual dietary ingredients were collected at feeding; representative orts (6.25%) were collected 23.5 h after feeding. Feed samples were composited into one sample per period. Rumen samples and ruminal pH data were collected every 9 h from d 26 to 28 so that 8 samples were taken from each cow each period; samples represented every 3 h of a 24-h period to account for diurnal variation. In situ digestion of soybean hulls was used as an index of diet effects on ruminal fiber digestion on d 21 to 24 of each period.

Cows were milked thrice daily in a milking parlor, and milk was sampled and yield was recorded for every milking on d 25 to 28 of each period. Body weight and BCS were measured on d 1 of each period and d 28 of the last period. Body condition score was measured on a scale of 1 to 5 by 3 trained investigators according to Wildman et al. (1982).

Nutrient and Milk Analyses

The Penn State Particle Size Separator (2-sieve) was used to measure particle size for TMR and orts (Lammers et al., 1996). Diet ingredients were dried in

a 55°C forced-air oven for 72 h. Feed ingredients were analyzed for DM concentration, ground to pass through a 1-mm screen with a Wiley mill (Arthur H. Thomas, Philadelphia, PA), and composited by period. Ash concentration was determined after 5 h of oxidation at 500°C in a muffle furnace. Concentration of NDF was determined (Van Soest et al., 1991) in the presence of sodium sulfite and amylase with an Ankom Fiber Analyzer (Ankom Technology, Fairport, NY). Crude protein was determined by oxidation and detection of N₂ (Leco Analyzer; Leco Corp., St. Joseph, MI). Crude fat was determined by ether extract (AOAC, 2000, method 920.9). Starch was determined by α -amylase and glucoamylase digestion, followed by colorimetric glucose quantification with a commercial kit (Autokit Glucose; Wako Chemicals USA, Richmond, VA). Concentrations (except DM) of all nutrients were expressed as percentages of DM determined by drying at 105°C in a forced-air oven for more than 8 h. All analyses were performed in duplicate.

Milk samples were analyzed by Heart of America DHIA (Manhattan, KS) to determine concentrations of fat, true protein, lactose (B-2000 Infrared Analyzer; Bentley Instruments, Chaska, MN), urea nitrogen

(MUN spectrophotometer, Bentley Instruments), and somatic cells (SCC 500, Bentley Instruments). Energy-corrected milk yield was calculated as $0.327 \times \text{milk yield} + 12.86 \times \text{fat yield} + 7.65 \times \text{protein yield}$ (Dairy Records Management Systems, 2009), and SCM yield was calculated according to Tyrrell and Reid (1965).

Ruminal Fiber Digestion

Each of the 8 animals had 16 Dacron bags of soybean hulls (0.5 g) placed in their rumen at different time points over a 72-h period starting on d 21. Soybean hulls were used instead of WCGF because they provide a consistent, digestible source of NDF, allowing quantitative assessment of the associative effects of diets on NDF digestion. The soybean hulls used in this part of the experiment all came from the same batch and were ground to pass through a 1-mm screen with a Wiley mill (Arthur H. Thomas). Dacron bags (Ankom Technology) had dimensions of 5×10 cm; pore size was 50 μm . Bags were placed in the rumen in quadruplicate, in a mesh bag that was weighted, at time points that allowed for 12, 24, 48, or 72 h of ruminal digestion. On d 24, all 16 bags were removed from each animal for rinsing. Bags were rinsed in warm water ($\approx 30^\circ\text{C}$) in a series 80 washing machine (Kenmore, Hoffman Estates, IL). After rinsing, bags were dried in a forced-air oven at 55°C for 72 h for determination of DM. Bags were then transferred to an Ankom apparatus to determine NDF residue. Six samples of soybean hulls from the original batch that had not been subjected to ruminal degradation were similarly rinsed and then analyzed for DM and NDF concentration. Dry matter and NDF remaining in bags subjected to in situ digestion were compared with the DM and NDF content of these 6 samples, and DM and NDF disappearance was calculated as the difference between these respective values.

Rumen Environment

Grab samples of ruminal digesta were collected from 5 locations throughout the rumen: the ventral sac (2 locations), the cranial sac, the caudal dorsal sac, and the caudal ventral sac. Samples were mixed, and a representative subsample was strained through 4 layers of cheesecloth to obtain a fluid sample. Rumen fluid pH was measured with a portable pH meter (Orion Research, Boston, MA), and a 20-mL sample was frozen at -20°C until compositing. Rumen fluid was composited by cow period to yield an 8-mL sample, and 2 mL of 25% metaphosphoric acid was added. Composited samples were frozen, thawed, and centrifuged at $30,000 \times g$ for 20 min at room temperature, and the supernatant was collected for analysis of VFA and NH_3 .

Ammonia was determined colorimetrically with an autoanalyzer (Technicon Analyzer II; Technicon Industrial Systems, Buffalo Grove, IL). Ruminal VFA were measured with a gas chromatograph (Model 5890; Hewlett-Packard, Avondale, PA) with a flame ionization detector (compressed air flow was set at 200 mL/min, and hydrogen flow was set at 20 mL/min; Montgomery et al., 2008). The chromatograph was fitted with a $1.82 \text{ m} \times 6.35 \text{ mm}$ inside diameter glass column packed with GP 10% SP-1200/1% H_3PO_4 (Supelco #1-1965, Bellefonte, PA). The column was maintained at 130°C , the detector and injector were maintained at 250°C , and carrier gas (N_2) flow was 80 mL/min. Run time was approximately 5 min.

Statistical Analysis

In the first 2 periods of this trial, 2 cows were observed reaching into neighboring feed bunks. When efficiencies were calculated, distribution analysis showed these cows to be extreme outliers. Intake of these cows was deemed inaccurate, so intake, production, digestibility, and efficiency data of these 2 cows were omitted from analysis. Intake and efficiency data of their neighboring cows was perceived as inaccurate and omitted from analysis as well. With these data omitted, intake and efficiency data included 6, 7, 5, and 6 observations for the 0, 11, 23, and 34% WCGF treatments, respectively. For all other variables, 6, 7, 7, and 8 observations were included for the 0, 11, 23, and 34% WCGF treatments, respectively. Cows changed locations in the tie-stall barn on d 1 of period 3 to allow for one empty stall between each pair of neighboring animals.

Data were analyzed according to the following model using the REML procedure of JMP (version 8.0, SAS Institute, Cary, NC):

$$Y_{ijk} = \mu + T_i + P_j + C_k + e_{ijk},$$

where μ = overall mean, T_i = fixed effect of treatment ($i = 1$ to 4), P_j = random effect of period ($j = 1$ to 4), C_k = random effect of cow ($k = 1$ to 8), and e_{ijk} = residual error. The fixed effect of time also was included in the model to assess time-by-treatment interactions when analyzing in situ degradation of soybean hulls. Linear and quadratic effects of WCGF inclusion rate were tested. Treatment effects were declared significant at $P < 0.05$. Tendencies for treatment effects were declared at $P < 0.10$.

RESULTS AND DISCUSSION

Ingredient compositions of treatment diets used in this study were similar to those in treatment diets used

Table 3. Effects of level of wet corn gluten feed (WCGF) on performance of lactating Holstein cows

Item ¹	Dietary WCGF (DM basis)				SEM	P-value	
	0%	11%	23%	34%		Linear	Quadratic
DMI (kg/d)	26.7	25.9	29.3	29.7	1.6	0.03	0.55
Yield (kg/d)							
Milk	36.8	37.0	40.1	38.9	2.6	0.007	0.28
Milk fat	1.37	1.39	1.49	1.44	0.11	0.06	0.21
Milk protein	1.11	1.14	1.21	1.21	0.08	0.01	0.49
Milk lactose	1.85	1.85	2.02	1.95	0.13	0.01	0.32
SCM	35.2	35.7	38.5	37.2	2.5	0.01	0.19
ECM	38.2	38.8	41.7	40.4	2.8	0.01	0.19
Milk fat (%)	3.65	3.76	3.72	3.67	0.11	0.93	0.23
Milk protein (%)	3.02	3.07	3.05	3.11	0.08	0.13	0.80
Milk lactose (%)	5.02	5.00	5.03	5.01	0.03	0.94	0.96
SCC (1,000/mL)	40.6	64.1	31.9	50.2	14.8	0.96	0.87
MUN (mg/dL)	17.2	16.3	16.3	17.3	0.90	0.83	0.08
ECM/DMI (kg/kg)	1.44	1.50	1.34	1.29	0.06	0.007	0.20
NE _p /DMI ² (Mcal/kg)	1.02	1.05	0.97	0.98	0.06	0.33	0.75
BW change (kg/28 d)	45.6	14.3	9.2	29.7	17.6	0.65	0.73
BCS change/28 d	-0.02	0.09	0.15	0.25	0.07	0.02	0.92

¹Total n = 24 for DMI, ECM/DMI, and NE_p/DMI; n = 25 for SCC; n = 28 for other variables. The SEM shown is the mean of treatment SEM.

²NE_p = net energy for productive use, defined as milk energy plus energy for BCS gain.

by Brouk et al. (2006). Nutrient composition remained relatively similar across all 4 treatments, except DM and ash concentrations, which were slightly greater for the diet without WCGF (Table 2). The WCGF used in this study was supplied from a single source (Sweet Bran; Cargill Inc., Blair, NE), and nutrient variability of this product, across the 4 collection periods, was low (Table 1).

As the inclusion rate of WCGF increased, DMI increased linearly from 26.7 to 29.7 kg/d ($P < 0.03$; Table 3). Because intake is influenced by specific gravity of feedstuffs (Kaske and Engelhardt, 1990), particle size (Beauchemin and Yang, 2005), and rate of fermentation (Allen, 2000), it is no surprise that DMI increased in diets with greater concentrations of WCGF. Studies using similar diets indicated greater passage rates in diets with more WCGF and less forage (Allen and Grant, 2000; Boddugari et al., 2001). Quicker passage leads to decreased rumen fill per unit of feed intake, which could have stimulated greater feed intake in this study. Other researchers have reported cows consuming WCGF to have greater DMI (VanBaale et al., 2001; Kononoff et al., 2006), but these results are in contrast with studies reporting a decrease in DMI (Staples et al., 1984; Macleod et al., 1985; Boddugari et al., 2001) as well as some indicating that WCGF inclusion does not affect DMI (Armentano and Dentine, 1988; Gunderson et al., 1988; Schroeder, 2003).

Milk yield increased linearly from 36.8 to 38.9 kg/d as greater proportions of WCGF were offered ($P < 0.007$; Table 3); however, concentrations of milk components ($3.70 \pm 0.11\%$ fat, $3.06 \pm 0.08\%$ protein, 5.02

$\pm 0.03\%$ lactose, mean $\pm$ SEM) were not affected ($P > 0.13$; Table 3). Because of the increases in milk volume, yields of fat, protein, and lactose were greater as WCGF was added (Table 3). The increases in milk and milk component yields led to greater SCM ($P < 0.01$) and ECM ($P < 0.01$) production (Table 3). Similar increases in milk and milk component yields have been reported when WCGF replaced dietary forages (Boddugari et al., 2001; VanBaale et al., 2001; Kononoff et al., 2006). The total energy used for productivity, which includes production of milk and change in BCS, linearly increased as WCGF inclusion rate increased ($P < 0.001$; Figure 1). This is not surprising because DMI was greater for cows consuming greater concentrations of WCGF, which likely resulted in greater consumption of energy. Feed efficiency, measured as ECM/DMI, linearly declined as more WCGF was added to diets ($P < 0.007$; Table 3). Changes in feed efficiency have not commonly been observed when feeding increasing dietary levels of WCGF (Armentano and Dentine, 1988; Schroeder, 2003; Kononoff et al., 2006); furthermore, previously observed changes in efficiency have been increases (Gunderson et al., 1988; Boddugari et al., 2001; VanBaale et al., 2001). Treatments did not affect energy efficiency ($P > 0.33$, Table 3), measured as NE for productive use divided by DMI. Therefore, when milk production efficiency dropped in diets with greater WCGF, energy was not lost; it was instead partitioned toward body condition.

The inclusion rate of WCGF had a quadratic effect on MUN. This response did not correspond with treatment effects on dietary CP or milk protein but reflected

Table 4. Effects of level of wet corn gluten feed (WCGF) on rumen environment of lactating Holstein cows

Item ¹	Dietary WCGF (DM basis)				SEM	P-value	
	0%	11%	23%	34%		Linear	Quadratic
Total VFA (mM)	168.6	163.8	160.1	165.0	4.5	0.26	0.09
Acetate (mM)	97.2	90.6	87.1	84.6	2.4	<0.001	0.15
Propionate (mM)	34.4	37.8	36.8	43.1	1.3	<0.001	0.15
Butyrate (mM)	25.9	26.0	25.3	26.9	1.1	0.32	0.43
Isobutyrate (mM)	2.10	2.11	2.08	2.16	0.08	0.59	0.60
Valerate (mM)	4.38	4.76	4.90	5.84	0.26	<0.001	0.02
Isovalerate ² (mM)	3.45	3.36	3.11	2.56	0.31	0.001	0.16
NH ₃ (mM)	16.2	13.1	12.9	15.7	1.2	0.69	0.01
pH	6.18	6.12	6.14	5.91	0.06	0.001	0.07
24-h in situ NDF disappearance (%)	58.0	48.0	37.6	46.4	2.64	0.004	<0.001

¹Total n = 28 for all variables; the SEM shown is the mean of treatment SEM.

²Includes 3-m-butyrate and 2-m-butyrate.

changes noted in ruminal ammonia concentrations (Table 4). Because a substantial portion of MUN is derived from ruminal ammonia being absorbed, converted to urea in the liver, and then secreted in milk, it is logical that these concentrations coincide.

As WCGF was added to the diet over 11% of DM, forage was removed. It has been demonstrated in many studies that nonforage fiber (e.g., WCGF) is fermented more rapidly in the rumen than forage fiber (Armentano and Pereira, 1997; Firkins, 1997). Cows fed more fermentable diets have greater fat deposition because of increased lipogenesis in adipose tissue (Oba and Allen, 2003). This likely explains the linear increase in BCS change as greater proportions of WCGF were fed ($P < 0.02$, Table 3). Body weight change was not affected by treatment ($P \geq 0.65$) and did not correspond with changes in BCS. With the dietary treatments used in this study, effects on DMI and expected differences in passage rate from the rumen could have resulted in treatment effects on gut fill, which would complicate interpretation of weight-change data. Conversely, Nikkhah et al. (2008) recently demonstrated that BCS provides little information about internal fat stores, and changes in BW may be a better reflection of total tissue accretion than BCS if gut fill was not altered. However, given the treatments used in this study and the relatively stable BW of cows, we expect that discrepancies between BW change and BCS change were most likely due to difference in gut fill, and we considered treatment effects on BCS to be meaningful.

Substituting WCGF for portions of corn silage, alfalfa, corn grain, and soybean meal kept dietary NDF concentrations similar ($\approx 30\%$), but the effectiveness of that fiber can be questioned (Armentano and Pereira, 1997). Table 5 shows particle size data of the TMR and orts. All 4 diets had a relatively small mean particle size. The proportion of TMR particles greater than 8 mm declined in diets with greater WCGF inclusion

rates. As expected, this increased the proportion of small particles (less than 8 mm) in these diets. In all diets, the mean percentage of particles greater than 19 mm was around 3%; this is low, but it is within current recommendations for a lactating cow TMR (Heinrichs and Kononoff, 2002). However, according to these same guidelines, all 4 treatment diets contained an insufficient proportion of particles between 8 and 19 mm.

An adequate supply of long particles is necessary for healthy rumen function and maintenance of ruminal pH (Lammers et al., 1996). Diets lacking long particles generally are more fermentable (Grant et al., 1990),

Figure 1. Total energy partitioned to milk production and BCS change in Holstein cows fed increasing levels of wet corn gluten feed (WCGF). As WCGF was added, total productive energy linearly increased ($P < 0.001$). Body condition score loss was assigned an energetic value of 368 Mcal/unit, and BCS gain was assigned 459 Mcal/unit (NRC, 2001). Milk energy was calculated according to Tyrrell and Reid (1965) [milk energy = $(41.63 \times \% \text{ fat}) + (24.13 \times \% \text{ protein}) + (21.60 \times \% \text{ lactose}) - 11.72$].

Table 5. Effects of level of wet corn gluten feed (WCGF) on particle size separation of diets and orts (% as-fed basis) fed to lactating Holstein cows¹

Sample	Size	Dietary WCGF (DM basis)			
		0%	11%	23%	34%
TMR	>19 mm	3.85 ^a	3.25 ^{ab}	2.97 ^{ab}	2.36 ^b
	19–8 mm	29.6 ^a	29.6 ^a	27.2 ^b	24.2 ^c
	<8 mm	66.6 ^a	67.2 ^a	69.9 ^b	73.4 ^c
Orts ²	>19 mm	4.23	5.07	3.85	1.50
	19–8 mm ³	27.4	30.0	30.6	23.7
	<8 mm ³	70.6	64.9	65.5	74.7

^{a–c}Means within a row not bearing a common superscript letter are significantly different by Tukey's Honestly Significant Difference ($P < 0.05$).

¹Measured using a 2-sieve Penn State Particle Separator (Lammers et al., 1996). Total n = 8 per treatment.

²No significant differences were detected ($P > 0.15$) between the TMR and orts for each fraction across treatment diets.

³One outlier removed.

which can lead to greater acid production; this is a potential explanation for the linear drop ($P < 0.001$) in ruminal pH as WCGF was added to the diets (Table 4). Excessive acid production often is attributed to starch in dairy rations; however, the diet with the lowest pH also had the lowest starch concentration, suggesting that acid production was likely unrelated to dietary starch content in this study. Because pH changes were likely related to particle size, if diets with more WCGF had contained a greater proportion of particles longer than 8 mm, rumination could have increased and possibly led to increased chewing activity. Increased chewing activity may have stimulated production of salivary buffer; therefore, ruminal pH might not have been affected (Kay, 1966; Balch, 1971). It must also be noted that even though adding WCGF depressed ruminal pH, milk fat production was not adversely affected. This suggests the diet with 34% WCGF still provided enough effective fiber to prevent rumen pH from decreasing drastically enough to cause milk fat depression. Alternatively, it is possible that compared with a high-starch diet, our 34% WCGF diet was less likely to cause milk fat depression simply because of differences in fermentation substrates. Fuentes et al. (2009) reported that high grain inclusion in a continuous-flow fermenter increased the flow of *trans*-10, *cis*-12 conjugated linoleic acid independent of changes in pH.

Analysis of orts showed no differences in particle size across the 4 treatments (Table 5). This suggests cows fed the 0 and 11% inclusion rates consumed more long particles. The long particles consumed were primarily from forages, which stimulated rumination and saliva production, explaining the higher pH for these treatments. Comparing particle size data of the orts and TMR showed no differences ($P > 0.15$) in the 3 fractions tested; this suggests animals did not sort. Because each diet contained a relatively small proportion of long

particles, sorting may not have been possible (DeVries et al., 2007), or the moisture level of each diet could have served as a binder, preventing sorting (Leonardi and Armentano, 2003).

Measures of ruminal fermentation are presented in Table 4. As expected, the lower pH observed as WCGF was added coincided with decreased ruminal acetate concentration ($P < 0.001$) and increased propionate and valerate concentrations ($P < 0.001$). Differences in diet particle size or ruminal fiber digestibility could have led to these effects (Krause and Combs, 2003). Quadratic effects were detected for concentrations of total VFA ($P < 0.09$) and ammonia ($P < 0.01$); cows fed 0 and 34% WCGF tended to have greater overall VFA and ammonia concentrations. The differences in concentration might suggest that ruminal absorption of these components was greater for cows fed 11 and 23% WCGF (Brown et al., 1960; Roffler et al., 1976) or that total production was greater for cows fed 0 and 34% WCGF. The dietary inclusion rate of WCGF did not affect butyrate and isobutyrate concentrations, but isovalerate decreased with WCGF additions. In general, this study shows that WCGF significantly affected the VFA profile, but other researchers have observed minimal effects (Firkins et al., 1985; Schroeder, 2003).

Soybean hulls have a highly digestible fiber fraction and minimal associative effects (Weidner and Grant, 1994); therefore, they were used to measure fiber digestion in the rumen as influenced by each diet. In situ digestibility of soybean hulls showed a significant diet-by-time interaction ($P < 0.001$). Although differences in NDF disappearance at 12, 48, or 72 h of ruminal incubation were not significant (data not shown), increasing WCGF quadratically affected ($P < 0.001$) in situ NDF disappearance at 24 h (Table 4); the diet with 23% WCGF had the least disappearance of soybean hull NDF. The pH and 24-h NDF disappearance

were not correlated ($R^2 = 0.0002$), suggesting that pH was not the primary cause of change in fiber digestion. Therefore, it is unclear how increasing WCGF inclusion negatively affected the in situ NDF digestion.

CONCLUSIONS

Results from this study demonstrate responses to WCGF that are consistent with recently published research. However, rather than indicating that WCGF improves the rumen environment for fiber-digesting bacteria, production responses to WCGF in this study seem to have been driven by increased DMI. Increased DMI is likely caused by decreased rumen fill due to feeding a source of NDF with smaller particles and a more rapid disappearance rate. As a whole, adding WCGF to dairy rations likely will increase ECM yield; however, this increase in production is driven, at least in part, by an increase in DMI.

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