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# Maximal Replacement of Forage and Concentrate with a New Wet Corn Milling Product for Lactating Dairy Cows[1]

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## ABSTRACT

Three experiments were conducted to determine the maximal amount of concentrate and forage that could be replaced with a new wet corn milling product. The corn milling product contained 23.1% crude protein, 9.9% ruminally undegradable protein, 13.7% acid detergent fiber, 40.3% neutral detergent fiber, and 2.6% ether extract (% of dry matter; DM). In experiment 1, 16 Holstein cows were assigned to one of four diets in a replicated 4 × 4 Latin square design with 28-d periods. The four diets contained 54.3% forage (alfalfa:corn silages, 1:1 DM basis) with the wet corn milling product replacing 0, 50, 75, or 100% of the concentrate portion (corn and soybean meal) of the diet (DM basis). The diets containing wet corn milling product resulted in 7.8% lower DM intake, equivalent milk production (28.5 kg/d), and 13.6% greater efficiency of 4% fat-corrected milk (FCM) production than the control diet. There was no effect of diet on ruminal pH. In experiment 2, 16 Holstein cows were assigned to one of four diets in a replicated 4 × 4 Latin square design with 28-d periods. The 100% concentrate replacement diet from experiment 1 was used as control diet. For the test diets, forage was replaced with 15, 30, or 45% of the corn milling product (DM basis). Efficiency of FCM production (1.16) was not affected by diet. Rumination time was reduced for the 30 and 45% forage replacement diets, but ruminal pH was unaffected. In experiment 3, 30 Holstein cows were assigned at parturition to either a control diet (no corn milling product) or a diet containing 40% corn milling feed in place of both forage and concentrate (optimal levels from experiments 1 and 2) for 9 wk. The diet containing corn milling feed resulted in 21% greater efficiency of FCM production than the control diet. These results indicate that a new feed product based on wet corn milling ingredients has the potential to effectively replace all of the concentrate and up to 45% of the forage in the diet for lactating dairy cows.
(**Key words:** wet corn milling, corn gluten feed, dairy cows, forage and concentrate replacement)

**Abbreviation key: CMP** = wet corn milling feed product, **CNCPM** = Cornell Net Carbohydrate Protein Model, **WCGF** = wet corn gluten feed.

## INTRODUCTION

Because of their low lignin content and highly digestible fiber, nonforage sources of fiber can supply energy needed for lactation without the ruminal acid load caused by rapidly fermented starchy concentrates. Nonforage sources of fiber also may partially replace forage fiber in situations in which forage availability is limited if the physical effectiveness of total ration NDF remains adequate for rumination. Wet corn gluten feed (**WCGF**) is a readily available nonforage source of fiber that is primarily a mixture of corn bran and fermented corn extractives (steep liquor). Although WCGF contains 35 to 45% NDF, it only has 2 to 3% lignin, and consequently is a source of highly digestible fiber.

A summary of beef feedlot research (Stock et al., 1999) indicated that efficiency of gain was improved by 5.1% when diets containing 25 to 50% WCGF (corn bran:steep liquor, 1:1 DM basis) were compared with dry-rolled corn. This positive response was likely due to reduced ruminal acidosis, increased DMI, and also to a reduction in negative associative effects of ruminally fermentable starch on fiber digestion.

Ruminal acidosis is a significant concern when feeding dairy cows because of the need for optimal ruminal fiber digestion in the presence of substantial amounts of starchy concentrate feeds. Corn bran is rapidly and extensively digested in the rumen (Allen and Grant, 2000). The in situ rate of NDF digestion for WCGF has been measured as 6.8%/h, whereas rate of ruminal starch digestion ranges between 10 and 35%/h (Allen and Grant, 2000). Consequently, the dilution of nonfiber carbohydrates with fiber from WCGF would result in slower

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rates of fermentation, reduced acid load in the rumen per unit of fermentation time, and the ability to feed a highly digestible diet with low risk of ruminal acidosis.

One problem with the design of some previous research that evaluated WCGF for dairy cows has been that diets were balanced for CP, but not metabolizable protein. Wet corn gluten feed contains twice as much CP as corn, but less metabolizable protein (Krishnamoorthy et al., 1982; Stock et al., 1999). Thus, control diets containing corn grain, which use soybean meal or distillers grains to balance for CP, may contain CP concentrations similar to WCGF diets, but these control diets also contain substantially greater amounts of metabolizable protein. If metabolizable protein is not adequate for diets containing WCGF, erroneous conclusions may be made concerning the nutritional value of WCGF. Several studies have indicated that approximately 20% dietary WCGF (DM basis) is optimal for milk production (Droppo et al., 1982; Gunderson et al., 1988; Schroeder and Park, 1997); however, metabolizable protein may have been limiting milk production rather than energy or effective NDF.

Our goals were to 1) develop a new WCGF product based on ingredients from the wet corn milling process to enhance the metabolizable protein content of WCGF, 2) to determine the maximal percentage of replacement of dietary concentrate (experiment 1) and forage (experiment 2) with this new feed product, and 3) to determine the impact on early lactation DMI and milk production of feeding the optimal amount of wet corn milling product (from experiments 1 and 2). Our hypothesis was that a properly formulated WCGF product could be fed in much larger amounts than currently practiced by the dairy industry.

**Table 1**. Ingredient and chemical composition of diets for experiment 1.

| Item | Concentrate replacement with CMP[1] (% of DM) | | | |
|---|---|---|---|---|
| | 0 | 50 | 75 | 100 |
| | % of DM | | | |
| Ingredients | | | | |
| Alfalfa silage[2] | 27.1 | 27.1 | 27.1 | 27.1 |
| Corn silage[3] | 27.1 | 27.1 | 27.1 | 27.1 |
| Corn grain, ground | 27.2 | 14.6 | 6.8 | . . . |
| Soybean meal, 46.5% CP | 15.8 | 7.6 | 4.0 | . . . |
| CMP | . . . | 21.9 | 33.8 | 45.3 |
| Mineral and vitamin mix[4] | 2.8 | 1.7 | 1.2 | 0.5 |
| Chemical composition | | | | |
| DM % | 58.8 | 56.9 | 56.1 | 55.2 |
| CP | 18.1 | 18.0 | 18.1 | 18.1 |
| RUP[5] | 5.9 | 6.0 | 5.9 | 5.9 |
| MP[6] | 14.1 | 12.8 | 12.3 | 11.9 |
| ADF | 18.1 | 19.2 | 21.4 | 22.4 |
| NDF | 28.2 | 35.4 | 38.2 | 41.6 |
| NFC[7] | 43.2 | 36.5 | 32.9 | 29.4 |
| Ether extract | 3.1 | 2.9 | 2.7 | 2.6 |

[1]Corn milling feed product contained 23.1% CP, 9.9% RUP, 13.7% ADF, 40.3% NDF, and 2.6% ether extract (DM basis).

[2]Alfalfa silage contained 45% DM, 20.0% CP, 31.0% ADF, and 42.0% NDF (DM basis).

[3]Corn silage contained 35% DM, 8.1% CP, 22.0% ADF, and 42.0% NDF (DM basis).

[4]Composition of supplement differed by diet, but provided 1.00% Ca, 0.50% P, 0.36% Mg, 1.3% K, 120,000 IU/d of vitamin A, 24,000 IU/d of vitamin D, and 800 IU/d of vitamin E in the total ration DM.

[5]Calculated using a value of 9.9% RUP for CMP measured in vitro (Britton et al., 1978) and values reported by NRC (1989) for other ingredients.

[6]Metabolizable protein supplied by these diets as predicted by Cornell Net Carbohydrate and Protein Model (1994).

[7]Calculated according to Van Soest et al. (1991).

## MATERIALS AND METHODS

The wet corn milling feed product (**CMP**) developed for these experiments was composed of corn bran, fermented corn extractives, corn germ meal, and additional sources of RUP to increase the metabolizable protein content of the product. The CMP contained 23.1% CP, 43.0% RUP (% of CP), 13.7% ADF, 40.3% NDF, and 2.6% ether extract (DM basis). For comparison, the nutrient composition of WCGF provided by NRC (1989) is 25.6% CP, 26.0% RUP (% of CP), 12.0% ADF, 45.0% NDF, and 2.4% ether extract (DM basis); the typical nutrient profile of WCGF from the wet milling plant (Cargill Corn Milling, Blair, NE) that provided the CMP is 22.5% CP, 30.0% RUP (% of CP), 14.0% ADF, 43.0% NDF, and 2.5% ether extract (DM basis; unpublished data, Ruminant Nutrition Laboratory, Univ. of Nebraska, Lincoln). For experiments 1 and 2, the product was delivered to the Dairy Research Unit approximately weekly, and each load was sampled for chemical composition; for experiment 3, sufficient CMP for the entire trial was stored in a plastic silage bag before the beginning of the experiment.

### Experiment 1

***Cows and diets.*** Sixteen Holstein cows (four primiparous; four ruminally fistulated) were assigned to one of four diets in a replicated 4 × 4 Latin square design with 28-d periods. Cows were housed in a tie-stall barn and averaged 64 ± 8 DIM when they were assigned to diets. The four diets (Table 1) contained 54.3% forage (alfalfa:corn silages, 1:1 DM basis). The concentrate portion of the control diet consisted of ground corn grain, soybean meal, and a mineral and vitamin mix. The concentrate portion of the control diet was replaced (DM basis) with 0, 50, 75, or 100% of the CMP. The chemical composition of the diets is shown in Table 1. Diets were formulated to be isonitrogenous (18.1% CP, DM basis) and to contain similar RUP (5.9%, DM basis).

Experimental periods were 28 d; the last 7 d were used for sample and data collection. Diets were fed once daily in amounts to ensure 10% orts. Amounts offered and orts were recorded daily. Body weight was measured each week immediately after the a.m. milking. Cows were fistulated and housed under conditions described in animal use protocols approved by the Institutional Animal Care and Use Committee at the University of Nebraska.

***Sample collection and analyses.*** Individual feed ingredients and TMR samples were collected daily during the last week and composited for each period. Samples were oven-dried (60°C), ground through a Wiley mill (1-mm screen; Arthur H. Thomas Co., Philadelphia, PA), and analyzed for CP (AOAC, 1990), amylase-modified (heat stable $\alpha$-amylase; ANKOM Tech. Corp., Fairport, NY) ash-free NDF with sulfite (Van Soest et al., 1991), ADF (Goering and Van Soest, 1970), and ether extract (AOAC, 1990). The RUP content of the CMP was measured in vitro (Britton et al., 1978).

Daily milk production was recorded electronically for all cows. Separate a.m. and p.m. milk samples were collected twice during wk 4 of each period and analyzed for percentage of fat, CP, and lactose (AOAC, 1990; Milko-Scan Fossomatic, Foss Food Technology Corp., Eden Prairie, MN). Calculation of milk composition was weighted according to a.m. and p.m. milk production.

To determine the total tract NDF and DM digestion, feed and fecal samples were collected daily for 7 d at the a.m. feeding for indirect estimates of digestibility by the protocol of Nakamura and Owen (1989). All feed and fecal samples were frozen and later composited before chemical analyses. Total tract NDF and ADF digestibilities were determined using the acid insoluble ash ratio technique (Van Soest et al., 1991).

To determine fractional rate of NDF digestion in the rumen of the CMP, 5-g samples of dried CMP (60°C, forced-air oven) were placed into Dacron bags. Samples were incubated in duplicate for 0, 4, 8, 12, 16, 24, 36, 48, and 72 h. Dacron bags were 10 cm × 20 cm with a mean pore size of 53 $\mu$m (ANKOM Tech. Corp., Fairport, NY). Samples of CMP were incubated in one cow for each diet during each period (total of four cows per diet). Upon removal from the rumen, bags were rinsed and dried at 60°C in a forced-air oven for 48 h. Bags were weighed and the residue was analyzed for amylase-modified, ash-free NDF. Kinetics of NDF digestion and potential extent of ruminal fiber digestion were calculated as described by Grant (1994).

The fractional passage rate of CMP NDF from the rumen was determined with Er as a rare earth marker. Some evidence suggests that rare earth markers migrate, but this movement would likely occur postruminally and not affect the relative ruminal passage kinetics reported. The NDF from CMP was soaked in a solution containing 87 mg of Er-acetate/g of DM in 7.5 ml of distilled water for 24 h and then soaked in 10 ml of 0.1 *M* acetic acid/g of DM for 6 h. Each fistulated cow was dosed with 100 g (DM basis) of labeled, undried CMP. Ruminal digesta samples were collected at 0, 6, 12, 24, 36, 48, 72, and 96 h postdosing. Samples were dried in a forced-air oven at 60°C for 48 h and ground through a 1-mm screen (Wiley mill). Erbium was extracted from the samples by 0.1 *M* diethylenetriaminepentaacetic acid solution (Karami et al., 1986). Erbium concentrations were determined by atomic absorption spectroscopy with an air-acetylene flame. Techniques described by Llamas-Lamas and Combs (1990) were used to calculate the ruminal escape rate of CMP NDF.

Total chewing, eating, and ruminating times were determined during the last week of each collection period. Chewing action of individual cows was recorded every 5 min for 24 h. Ruminal fluid samples were collected via ruminal fistula immediately beneath the ruminal mat at 4-h intervals for 24 h. Ruminal pH was determined immediately with a portable pH meter. Samples were frozen until analysis for VFA using GLC (Weidner and Grant, 1994).

## Experiment 2

***Cows and diets.*** Sixteen Holstein cows (four primiparous; four ruminally fistulated) were assigned to one of four diets in a replicated 4 × 4 Latin square design with 28-d periods. Cows were housed in a tie-stall barn and averaged 57 ± 12 DIM when they were assigned to treatment. The 100% concentrate replacement diet from experiment 1 was used as the control diet. The three test diets were formulated by replacing the forage portion of the control diet in increments of 15% up to a maximum of 45% replacement. Diets were fed once daily in amounts to ensure 10% orts. The chemical composition of the diets is in Table 2.

Sample collection and analyses were the same as for experiment 1. In addition, ruminal mat consistency was determined for the four diets at 3-h postfeeding during the last week of each period by the technique adapted from Welch (1982) as described by Weidner and Grant (1994). A 454-g weight was placed in the ventral rumen 1 h prior to measurement. Upon release of an exterior 1500-g weight, ascension of the 454-g weight through the ruminal mat was recorded every 10 s for 120 s. The ascension rate, in centimeters per second, was considered to be an indication of ruminal mat consistency.

## Experiment 3

Thirty Holstein cows (10 primiparous) were assigned within parity at 1 d after parturition to one of two diets:

**Table 2**. Ingredient and chemical composition of diets for experiment 2.

| Item | Forage replacement with CMP[1] (% of DM) | | | |
|---|---|---|---|---|
| | 0 | 15 | 30 | 45 |
| | % of DM | | | |
| Alfalfa silage[2] | 27.1 | 23.1 | 18.9 | 15.0 |
| Corn silage[3] | 27.1 | 23.1 | 18.9 | 15.0 |
| CMP | 45.3 | 53.4 | 61.6 | 69.6 |
| Mineral and vitamin premix[4] | 0.5 | 0.4 | 0.6 | 0.4 |
| Chemical composition | | | | |
| DM, % | 56.3 | 55.7 | 53.7 | 58.2 |
| CP | 18.3 | 18.9 | 19.3 | 19.9 |
| RUP[5] | 5.8 | 6.0 | 6.5 | 7.0 |
| MP[6] | 14.1 | 15.4 | 15.9 | 16.3 |
| ADF | 20.7 | 19.7 | 18.6 | 17.6 |
| NDF | 41.2 | 40.9 | 40.8 | 40.7 |
| NFC[7] | 29.3 | 28.6 | 27.7 | 27.0 |
| Ether extract | 2.6 | 2.6 | 2.5 | 2.4 |
| Particle distribution[8] | | | | |
| >19 mm | 9.3 | 7.0 | 5.2 | 5.9 |
| 19 mm to 8 mm | 46.9 | 46.0 | 26.3 | 28.3 |
| <8 mm | 43.8 | 47.0 | 68.5 | 65.8 |

[1]Corn milling feed product contained 23.1% CP, 9.9% RUP, 13.7% ADF, 40.3% NDF, and 2.6% ether extract (DM basis).

[2]Alfalfa silage contained 40% DM, 21.0% CP, 31.0% ADF, and 40.0% NDF (DM basis).

[3]Corn silage contained 34% DM, 8.3% CP, 22.0% ADF, and 44% NDF (DM basis).

[4]Mineral and vitamin supplement contained (DM basis) 3.5% Ca, 20.0% Na, 31.0% Cl, and 336,000 IU/kg vitamin A, 67,000 IU/kg of vitamin D, and 1,348 IU/kg of vitamin E.

[5]Calculated using a value of 9.9% RUP for CMP measured in vitro (Britton et al., 1978) and values reported by NRC (1989) for other ingredients.

[6]Metabolizable protein supplied by these diets as predicted by the Cornell Net Carbohydrate and Protein Model (1994).

[7]Calculated according to Van Soest et al. (1991).

[8]Particle distribution (% of as-is TMR) determined using the Penn State Forage Particle Separator (Lammers et al., 1996).

1) a control diet containing no CMP, or 2) a diet containing CMP in place of 50% of the concentrate and 30% of the forage (40% of total ration DM). The CMP diet was formulated to contain the optimal amount of CMP in place of forage and concentrate as determined from experiments 1 and 2. Diets were fed for 9 wk and were formulated to contain similar CP and RUP (Table 3).

Cows were housed in a tie-stall barn equipped with individual feed boxes. All diets were fed once daily in amounts to ensure 5% orts. Cows were removed twice daily from the barn for milking, exercise, and estrus detection for a total of 4 h. Feed samples were collected daily and composited weekly for nutrient analyses. Samples of individual dietary ingredients were oven-dried (60°C), ground through a 1-mm screen (Wiley mill), and analyzed for CP, ADF, NDF, and ether extract as described for experiment 1.

Daily DMI was determined by weighing the amount of the diet fed and orts daily. Net energy intake ($NE_I$) was derived by multiplying the weekly DMI by the calculated $NE_L$ concentration of the diet. All ingredient $NE_L$ values were obtained from the NRC (1989). Net energy required for body maintenance ($NE_M$) was calculated as $NE_M$ (Mcal/d) = kilograms of $BW^{0.75} \times 0.08$ (NRC, 1989). Net energy used for milk secretion ($NE_Y$) was calculated as $NE_Y$ (Mcal/d) = milk production (kilograms) × [0.3512 + (0.0962 × % milk fat)] (Lucy et al., 1991). Net energy balance (NEB) was calculated as NEB = $NE_I - NE_M - NE_Y$ (Lucy et al., 1991).

Milk samples were collected twice weekly at the a.m. and p.m. milkings and were analyzed separately for fat, CP, and lactose as described for experiment 1. The BW was measured weekly immediately after the a.m. milk-

**Table 3**. Ingredient and chemical composition of diets for experiment 3.

| Item | Control | CMP[1] |
|---|---|---|
| | % of DM | |
| Ingredients | | |
| Alfalfa silage[2] | 25.4 | 17.5 |
| Corn silage[3] | 25.4 | 17.5 |
| Corn grain, ground | 29.8 | 19.5 |
| Soybean meal, 46.5% CP | 16.2 | 3.1 |
| Blood meal | 0.4 | . . . |
| CMP | . . . | 40.0 |
| Mineral and vitamin mix[4] | 2.8 | 2.4 |
| Composition | | |
| DM, % | 64.8 | 63.5 |
| CP | 18.1 | 18.3 |
| RUP[5] | 6.2 | 6.4 |
| MP[6] | 13.7 | 13.2 |
| ADF | 16.0 | 15.8 |
| NDF | 27.5 | 35.0 |
| NFC[7] | 43.6 | 35.1 |
| Ether extract | 3.4 | 3.1 |
| Particle distribution[8] | | |
| >19 mm | 9.5 | 5.5 |
| 19 mm to 8 mm | 47.0 | 28.5 |
| <8 mm | 43.5 | 66.0 |

[1]Corn milling feed product contained 23.1% CP, 9.9% RUP, 13.7% ADF, 40.3% NDF, and 2.6% ether extract (DM basis).

[2]Alfalfa silage contained 45% DM, 20.0% CP, 31.0% ADF, and 44% NDF (DM basis).

[3]Corn silage contained 39% DM, 8.2% CP, 22.5% ADF, and 42.3% NDF (DM basis).

[4]Mineral and vitamin supplement contained (DM basis) 7.9% Ca, 2.6% P, 1.8% Mg, 2.2% Na, 1,026 mg/kg of Zn, 7.8 mg/kg of Mn, 128 mg/kg of Ca, and 215,310, 23,070, and 1,400 IU per kilogram of vitamin A, D, and E, respectively.

[5]Calculated using a value of 9.9% RUP for CMP measured in vitro (Britton et al., 1978) and values reported by NRC (1989) for other ingredients.

[6]Metabolizable protein supplied by these diets as predicted by Cornell Net Carbohydrate and Protein Model (1994).

[7]Calculated according to Van Soest et al. (1991).

[8]Particle distribution (% of as-is TMR) determined using the Penn State Forage Particle Separator (Lammers et al., 1996).

ing and BCS (1 = emaciated to 5 = obese; Wildman et al., 1982) was recorded weekly by two people, and the scores were averaged.

### Statistical Analyses

Data for experiments 1 and 2 were analyzed as a replicated 4 × 4 Latin square with model effects for square, cow within square, period, treatment, and square × treatment using the GLM procedure of SAS (1996). A multiple Student's *t*-test was used to separate means for significant main effects. Significance was declared at $P < 0.10$ unless otherwise noted. Significant treatment effects for experiment 3 were determined with the GLM procedure of SAS (1996) using means for the entire 9-wk period. Significance was declared at $P < 0.05$ unless otherwise noted.

## RESULTS AND DISCUSSION

### Experiment 1

***Dietary composition.*** Diets provided between 108% (75% replacement with CMP) and 124% (control diet) of the metabolizable protein requirement (Table 1), except for the 100% concentrate replacement diet which supplied 101% of the predicted metabolizable protein requirement as calculated by the Cornell Net Carbohydrate and Protein Model (**CNCPM**; 1994) for a Holstein cow weighing 600 kg and producing 32 kg of 4% FCM. In addition, the AA balance (grams per day) calculated by the CNCPM (1994) indicated that all diets supplied at least 100% of the requirement for each AA. If similar diets had been formulated with WCGF, instead of CMP, they would have been deficient in metabolizable protein at the 50% replacement level. The NDF content of the diets increased with incremental replacement of concentrate with CMP and ranged from 28.2 (control) to 41.6% (100% replacement). Conversely, calculated nonfiber carbohydrate content ranged from 43.2% (control) to 29.4% (100% replacement).

***Feed intake and milk production.*** The DMI was reduced when cows were fed diets containing CMP at any level of concentrate replacement (% of BW basis; Table 4). Despite the reduction in DMI, consumption of NDF was increased for cows fed the 75 and 100% replacement diets reflecting their higher NDF content. Previous research with WCGF has shown mixed results for DMI, with some researchers finding reduced DMI for multi- and primiparous cows fed WCGF (Macleod and Grieve, 1983; Staples et al., 1984) and others (VanBaale et al., 2000) observing increased DMI for primiparous cows. One possible explanation for these results may be that primiparous cows consumed more DM, versus control cows, when they were fed diets containing 20 to 40% WCGF (DM basis). In contrast, multiparous cows declined in DMI when fed diets containing 20 to 40% WCGF versus a control diet (Droppo et al., 1982).

There was no effect of diet on milk, milk fat, milk lactose, or 4% FCM production (Table 5). There was no effect ($P > 0.20$) of parity among squares on milk yield response; cows responded to diet similarly regardless of parity. Due to reduced feed intake, cows fed the CMP diets had a greater efficiency of FCM production than cows fed the control diet. Milk protein production was reduced for cows fed the 75 and 100% concentrate replacement versus the control and 50% replacement diets (Table 5). We attribute this reduction in milk protein to reduced DMI for these cows, and particularly for the 100% replacement diet, to the fact that the diet provided only 101% of the predicted metabolizable protein requirement. Droppo et al. (1982) and Staples et al. (1984) also observed a similar decrease in protein concentration when increasing amounts of WCGF were fed. Presumably, if the CMP had contained slightly more metabolizable protein, or if DMI had been greater, then milk protein would not have been affected negatively. Milk protein was unaffected by the same 100% concentrate replacement diet in experiment 2, in which cows consumed 10% more DM, which supports this conclusion.

***Chewing activity and ruminal fermentation.*** Chewing activity has been a measure of forage physical

**Table 4**. Consumption of DM and NDF by cows in experiment 1.

| | Concentrate replacement with CMP[1] (% of DM) | | | | |
|---|---|---|---|---|---|
| Item | 0 | 50 | 75 | 100 | SE |
| DMI | | | | | |
| kg/d | 24.7[a] | 22.5[b] | 23.1[ab] | 21.8[b] | 0.9 |
| % of BW | 4.30[a] | 4.00[b] | 4.05[b] | 3.85[b] | 0.10 |
| NDF intake | | | | | |
| kg/d | 7.0[b] | 7.8[b] | 8.7[a] | 8.9[a] | 0.4 |
| % of BW | 1.22[b] | 1.39[b] | 1.53[a] | 1.57[a] | 0.06 |

[a,b]Means within a row with different superscripts differ ($P < 0.10$).

[1]CMP = Wet corn milling feed product.

**Table 5**. Milk yield and composition as influenced by diet in experiment 1.

| | Concentrate replacement with CMP[1] (% of DM) | | | | |
|---|---|---|---|---|---|
| Item | 0 | 50 | 75 | 100 | SE |
| Milk, kg/d | 30.4 | 30.5 | 30.8 | 29.5 | 0.9 |
| Milk fat | | | | | |
| % | 3.69 | 3.72 | 3.40 | 3.69 | 0.16 |
| kg/d | 1.07 | 1.17 | 1.10 | 1.12 | <0.01 |
| Milk protein | | | | | |
| % | 3.12[a] | 3.08[ab] | 2.83[b] | 2.90[b] | 0.1 |
| kg/d | 0.95[a] | 0.94[a] | 0.87[b] | 0.84[b] | <0.01 |
| Milk lactose | | | | | |
| % | 4.60 | 4.58 | 4.59 | 4.52 | 0.14 |
| kg/d | 1.48 | 1.39 | 1.41 | 1.33 | 0.005 |
| 4% FCM, kg/d | 28.7 | 29.1 | 27.9 | 28.1 | 0.1 |
| 4% FCM/DMI, kg/kg | 1.15[b] | 1.32[a] | 1.28[ab] | 1.32[a] | 0.05 |
| BW change, kg per 28 d | 29[a] | 13[b] | 9[b] | 12[b] | 5 |

[a,b]Means within a row with different superscripts differ ($P < 0.10$).

[1]CMP = Wet corn milling feed product.

form since the roughage value index was proposed by Balch (1971). Recently, rumination activity has been used as an estimate of the physical effectiveness of fiber sources at stimulating salivary secretion and ruminal buffering (Allen, 1997; Mertens, 1997). Table 6 summarizes chewing activity as influenced by diet for experiment 1. Time spent eating was similar for all diets. Time spent ruminating was significantly higher for 50, 75, and 100% concentrate replacement versus the control diet. The higher rumination activity for cows fed the CMP diets was related to higher NDF content of these diets. Interestingly, the 15% increase in rumination activity between the control and 100% replacement diets can be explained by the physically effective NDF value of WCGF measured by Allen and Grant (2000).

Averaged over 24 h, ruminal pH and acetate to propionate ratios were not different among diets (Table 7). The mean pH was greater than 6.00 for all diets, and all diets resulted in an acetate to propionate ratio in excess of 2.0, below which milk fat depression can occur (Davis, 1979). Staples et al. (1984) observed a linear increase in acetate to propionate ratios with increasing replacement of concentrate with WCGF. All diets contained 54.2% coarsely chopped silage and so large differences in ruminal pH among diets were not expected. Total VFA concentration was greater for the 75 and 100% concentrate replacement diets compared with the 0 and 50% diets.

***Digestion and passage of CMP.*** Table 8 summarizes the kinetics of digestion and passage of CMP and total tract NDF and DM digestibilities of the experimental diets. There was no effect of diet on in situ measurement of lag, fractional rate, or potential extent of NDF digestion from the CMP. The rate of NDF digestion averaged 4.8%/h and extent averaged 90.5% which compares favorably with previously reported values for WCGF of 4.7%/h and 92.6%, respectively (Allen and Grant, 2000). These digestion results reflect the similarities in ruminal pH across all the diets and confirm that the ruminal

**Table 6**. Chewing activity as influenced by diet in experiment 1.

| | Concentrate replacement with CMP[1] (% of DM) | | | | |
|---|---|---|---|---|---|
| Item | 0 | 50 | 75 | 100 | SE |
| Eating | | | | | |
| min/d | 157 | 152 | 162 | 157 | 11 |
| min/kg NDF intake | 18.9 | 16.8 | 18.5 | 18.5 | 1.3 |
| Ruminating | | | | | |
| min/d | 376[b] | 414[a] | 413[a] | 434[a] | 12 |
| min/kg NDF intake | 43.2[b] | 45.5[a] | 47.4[a] | 50.6[a] | 2.2 |
| Total chewing | | | | | |
| min/d | 533[b] | 566[ab] | 574[ab] | 591[a] | 18 |
| min/kg NDF intake | 62.1 | 62.3 | 65.4 | 69.1 | 3.0 |

[a,b]Means within a row with different superscripts ($P < 0.10$).

[1]CMP = Wet corn milling feed product.

**Table 7**. Ruminal pH and VFA concentrations as influenced by diet for experiment 1.

| | Concentrate replacement with CMP[1] (% of DM) | | | | |
|---|---|---|---|---|---|
| Item | 0 | 50 | 75 | 100 | SE |
| Ruminal pH[2] | 6.14 | 6.06 | 6.06 | 6.15 | 0.09 |
| VFA, mol/100 mol | | | | | |
| Acetate (A) | 56.3 | 55.9 | 57.8 | 60.6 | 1.1 |
| Propionate (P) | 18.3 | 18.2 | 20.4 | 19.9 | 0.6 |
| Isobutyrate | 1.1 | 0.8 | 0.8 | 0.9 | <0.1 |
| n-butyrate | 9.3 | 9.1 | 9.5 | 10.2 | 0.2 |
| Isovalerate | 1.3 | 1.0 | 1.1 | 1.1 | <0.1 |
| n-valerate | 1.5 | 1.5 | 1.8 | 2.0 | 0.1 |
| Total VFA, m*M*/L | 87.8[b] | 86.4[b] | 91.4[a] | 94.5[a] | 1.8 |
| A:P | 3.09 | 3.09 | 2.83 | 3.02 | 0.07 |

[a,b]Means within a row with different superscripts differ ($P < 0.10$).

[1]CMP = Wet corn milling feed product.

[2]Mean pH and VFA from measurements taken every 4 h for 24 h.

environment was favorable for fiber fermentation. The fractional passage rate of CMP fiber from the rumen was unaffected by diet and averaged 5.93%/h. The similar passage rate reflects the similar content of forage and fermentability (buoyancy) of particles among diets.

The total tract NDF and DM digestibilities were not different across the diets (Table 8). Although not significant in this experiment, the 7.8% increase in DM digestibility for the CMP diets versus the control diet, plus the greater VFA concentration, may explain the increased efficiency of FCM production observed in this experiment.

In conclusion, for experiment 1, the CMP product has the potential to replace 100% of the concentrate mix for lactating dairy cows fed diets containing 54% forage. This level of concentrate replacement amounts to 45.3% of the dietary DM, which is substantially greater than the levels that previous studies have evaluated (Staples et al., 1984; Gunderson et al., 1988; VanBaale et al., 2000).

## Experiment 2

***Dietary composition.*** The 100% concentrate replacement diet from experiment 1 consisting of 54.2% forage, 45.3% CMP, and 0.5% vitamin and mineral supplement was used as the control diet. The forage portion of the control diet was replaced in increments of 15% up to a maximum of 45% replacement. So, the treatment diets consisted of 46.2, 37.8, and 30% forage (DM basis) and 53.4, 61.6, and 69.6% CMP (Table 2).

Diets contained between 111% (15% forage replacement) and 125% (45% forage replacement) of the metabolizable protein requirement (Table 7), except for the 0% forage replacement diet, which supplied 101% of the predicted metabolizable protein requirements as calcu-

**Table 8**. Measures of NDF digestion and passage of CMP[1] in experiment 1.

| | Concentrate replacement with CMP (% of DM) | | | | |
|---|---|---|---|---|---|
| Item | 0 | 50 | 75 | 100 | SE |
| Lag[2], h | 0.1 | 0 | 0 | 0 | <0.1 |
| $K_d$,[3] %/h | 5.20 | 5.00 | 4.00 | 4.80 | 0.26 |
| PED,[4] % | 91.2 | 91.4 | 89.8 | 89.6 | 0.5 |
| $r^2$ | 0.95 | 0.98 | 0.95 | 0.94 | |
| $K_p$,[5] %/h | 5.53 | 6.32 | 5.92 | 6.00 | 0.35 |
| TTD,[6] % | | | | | |
| NDF | 55.5 | 60.9 | 53.8 | 55.2 | 1.6 |
| DM | 63.7 | 69.2 | 71.3 | 65.4 | 1.7 |

[1]Wet corn milling feed product.

[2]Discrete lag time prior to NDF digestion.

[3]Fractional rate of NDF digestion.

[4]Potential extent of NDF digestion.

[5]Fractional rate of NDF passage from the rumen.

[6]Total tract digestibility.

**Table 9**. Consumption of DM and NDF by cows in experiment 2.

| | Forage replacement with CMP[1] (% of DM) | | | | |
|---|---|---|---|---|---|
| Item | 0 | 15 | 30 | 45 | SE |
| DMI | | | | | |
| kg/d | 24.2 | 25.6 | 25.3 | 25.4 | 0.9 |
| % of BW | 3.97 | 4.03 | 4.10 | 4.06 | 0.10 |
| NDF intake | | | | | |
| kg/d | 9.9 | 10.1 | 10.4 | 10.3 | 0.3 |
| % of BW | 1.63 | 1.65 | 1.68 | 1.65 | 0.04 |

[1]CMP = Wet corn milling feed product.

lated by the CNCPM (1994) for a 600-kg Holstein cow producing 32 kg/d of 4% FCM. The excess metabolizable protein reflected that we were replacing a silage mix of 14.6% CP with CMP of 23.1% CP. We kept the ratio of alfalfa to corn silage constant for this experiment, but realistically the ratio could be changed to avoid excessive amounts of metabolizable protein. In addition, the AA balance (grams per day) calculated by the CNCPM (1994) indicated that all diets supplied at least 100% of the requirement for each AA. The NDF content of the diets ranged from 41.2 for the control to 40.7% for the 45% forage replacement diet, reflecting the similar NDF content of the silage mix and the CMP. The particle distribution (Table 2) indicated that the control diet contained adequate long particles (9.3% greater than 19 mm), but the CMP diets contained only 5 to 7% long particles, which ordinarily is considered to be deficient (Lammers et al., 1996). The nonfiber carbohydrate content ranged from 29.3% (0% replacement) to 27.0% (45% replacement).

***Feed intake and milk production.*** There was no effect of forage replacement with CMP on DM or NDF intake (Table 9). This differs from replacement of concentrate for which we observed a reduction in DMI (Table 4). Milk yield increased with CMP replacement of forage (Table 10), which likely reflected the increased nutrient digestibility of CMP versus forage as well as the energy from the fermented corn extractives that make up a portion of the CMP.

Milk fat concentration was lower for cows fed the 45% forage replacement diets compared with cows fed the control diet, although milk fat production was unchanged (Table 10). The reason for the decrease in fat percentage could be because of the particle size differences between the CMP and the forages, despite similar NDF contents. Dairy cows require a minimum particle length in the diet to maintain normal chewing activity, ruminal pH, and milk fat synthesis (Grant et al., 1990; Shaver et al., 1986). The 45% forage replacement diet was likely borderline in supplying physically effective NDF as judged by milk fat being less than milk protein percentage. However, 4% FCM production was unaffected by diet, and efficiency of FCM production was similar for all diets (Table 10). Cows fed the 30 and 45% forage replacement diets gained more BW per 28-d period than did cows fed the control or the 15% replace-

**Table 10**. Milk yield and composition as influenced by diet in experiment 2.

| | Forage replacement with CMP[1] (% of DM) | | | | |
|---|---|---|---|---|---|
| Item | 0 | 15 | 30 | 45 | SE |
| Milk, kg/d | 29.2[b] | 30.4[ab] | 31.4[a] | 31.1[a] | 1.2 |
| Milk fat | | | | | |
| % | 3.70[a] | 3.52[ab] | 3.50[ab] | 3.21[b] | 0.10 |
| kg/d | 1.08 | 1.07 | 1.10 | 1.00 | 0.02 |
| Milk protein | | | | | |
| % | 3.24 | 3.25 | 3.28 | 3.31 | 0.08 |
| kg/d | 0.94 | 0.98 | 1.03 | 1.03 | 0.02 |
| Milk lactose | | | | | |
| % | 4.88 | 4.89 | 4.84 | 4.86 | 0.02 |
| kg/d | 1.42 | 1.48 | 1.52 | 1.51 | 0.02 |
| 4% FCM, kg/d | 28.0 | 28.5 | 29.6 | 28.6 | 0.7 |
| 4% FCM/DMI, kg/kg | 1.17 | 1.16 | 1.17 | 1.13 | 0.02 |
| BW change, kg per 28 d | 3[b] | 12[b] | 20[a] | 24[a] | 7 |

[a,b]Means within a row with different superscripts differ ($P < 0.10$).

[1]CMP = Wet corn milling feed product.

**Table 11**. Chewing activity as influenced by diet in experiment 2.

| Item | Forage replacement with CMP[1] (% of DM) 0 | 15 | 30 | 45 | SE |
|---|---|---|---|---|---|
| Eating | | | | | |
| min/d | 171 | 178 | 180 | 193 | 12 |
| min/kg of NDF intake | 17.2 | 18.5 | 16.8 | 19.0 | 1.6 |
| Ruminating | | | | | |
| min/d | 445 | 427 | 411 | 403 | 22 |
| min/kg of NDF intake | 46.0[a] | 44.3[ab] | 39.2[b] | 39.0[b] | 2.6 |
| Total chewing | | | | | |
| min/d | 616 | 605 | 590 | 596 | 24 |
| min/kg of NDF intake | 63.2 | 62.8 | 56.0 | 58.0 | 3.4 |

[a,b]Means within a row with different superscripts differ ($P < 0.10$).
[1]CMP = Wet corn milling feed product.

ment diets. Usually, cows experiencing reduced milk fat also gain weight more rapidly (Grant et al., 1990). Milk protein production was not affected by diet (Table 10), which indicates that we successfully met the metabolizable protein requirements for these cows.

***Chewing activity and ruminal fermentation.*** The physical effectiveness of fiber from any feed is related to its particle size and fiber content (Grant, 1997; Weidner and Grant, 1994). Although the NDF content of WCGF is comparable to that of alfalfa and corn silage, its ability to stimulate chewing and saliva secretion is limited. Table 11 presents chewing activity as influenced by CMP replacement of forage. There was no effect of CMP replacement of forage on eating activity. However, rumination (minutes per kilogram of NDF intake) was reduced by 18% from the control to the 45% replacement diet. Actual time spent ruminating was decreased by only 42 min/d. For diets containing nonforage sources of fiber and minimal forage, dietary concentration of forage NDF, and particularly the particle size of the dietary forage, are crucial for stimulating rumination (Grant, 1997). When the dietary NDF from forage declines to < 60%, the residual dietary forage must have sufficient particle size because most nonforage sources of fiber do not stimulate chewing as effectively as long forage (Grant, 1997). Allen and Grant (2000) measured the physically effective NDF of WCGF to be approximately 13%, which explains the reduction in rumination time for the CMP diets.

Table 12 summarizes the ruminal pH and VFA concentrations as influenced by diet averaged over 24 h. Ruminal pH was above 6.0 for all diets. There were significant differences observed in acetate and total VFA concentrations, but they were small and of doubtful biological significance. As in experiment 1, all acetate to propionate ratios were greater than 2.0, although the 45% forage replacement diet had numerically the lowest ratio and also resulted in the least rumination time and milk fat percentage.

***Digestion and passage of CMP.*** Similar to experiment 1, there was limited effect of diet on in situ NDF digestion kinetics of CMP (Table 13). Fractional rate of

**Table 12**. Ruminal pH and VFA concentrations as influenced by diet for experiment 2.

| Item | Forage replacement with CMP[1] (% of DM) 0 | 15 | 30 | 45 | SE |
|---|---|---|---|---|---|
| Ruminal pH[2] | 6.13[a] | 6.01[b] | 6.13[a] | 6.06[ab] | 0.03 |
| VFA, mol/100 mol | | | | | |
| Acetate (A) | 48.7[ab] | 49.5[a] | 46.9[ab] | 45.4[b] | 0.9 |
| Propionate (P) | 18.4 | 21.1 | 19.3 | 20.2 | 0.6 |
| Isobutyrate | 0.8 | 0.8 | 0.8 | 0.8 | <0.1 |
| n-butyrate | 10.1 | 11.6 | 10.9 | 11.0 | 0.3 |
| Isovalerate | 1.1 | 1.1 | 1.2 | 1.0 | <0.1 |
| n-valerate | 1.9 | 2.2 | 2.0 | 2.1 | <0.1 |
| Total VFA, m*M*/L | 79.3[b] | 86.3[a] | 81.3[a] | 80.5[a] | 1.3 |
| A:P | 2.54 | 2.37 | 2.44 | 2.27 | 0.05 |

[a,b]Means within a row with different superscripts differ ($P < 0.10$).
[1]CMP = Wet corn milling feed product.
[2]Mean pH and VFA from measurements taken every 4 h for 24 h.

**Table 13**. Measures of NDF digestion of CMP[1] in experiment 2.

| | Forage replacement with CMP (% of DM) | | | | |
|---|---|---|---|---|---|
| Item | 0 | 15 | 30 | 45 | SE |
| Lag[2], h | 0 | 0.4 | 0.1 | 0 | 0.1 |
| $K_d$,[3] %/h | 5.8$^{a}$ | 5.4$^{ab}$ | 6.2$^{a}$ | 5.2$^{b}$ | 0.2 |
| PED,[4] % | 90.1 | 91.2 | 92.4 | 91.6 | 0.47 |
| $r^2$ | 0.98 | 0.95 | 0.92 | 0.95 | |
| $K_p$,[5] %/h | 6.03$^{b}$ | 7.13$^{ab}$ | 8.44$^{a}$ | 8.47$^{a}$ | 0.71 |
| TTD,[6] % | | | | | |
| NDF | 53.1$^{b}$ | 64.6$^{a}$ | 62.7$^{a}$ | 64.5$^{a}$ | 2.7 |
| DM | 66.2 | 71.7 | 74.4 | 69.2 | 1.8 |

[a,b]Means within a row with different superscripts differ ($P < 0.10$).

[1]Corn milling feed product.

[2]Discrete lag time prior to NDF digestion.

[3]Fractional rate of NDF digestion.

[4]Potential extent of NDF digestion.

[5]Fractional rate of NDF passage from the rumen.

[6]Total tract digestibility.

NDF digestion averaged 5.7%/h, and the potential extent of NDF digestion averaged 91.3%. Total tract digestibility of NDF was greater for diets in which CMP replaced forage than for the control diet. Although not significant, DM digestibility was 8.5% greater for CMP diets versus control. These changes in NDF digestibility reflect the greater digestibility of NDF from the CMP compared with forage NDF (Allen and Grant, 2000). Fractional rate of passage of CMP fiber particles from the rumen increased with decreasing forage content of the diet (Table 13). Previous measures of passage rate of WCGF ranged from 5.1 to 6.7%/h (Allen and Grant, 2000) and for soybean hulls ranged from 4.9 to 7.6%/h (Weidner and Grant, 1994). The extremely low content of forage likely explains the rapid passage rate of the CMP for the 30 and 45% forage replacement diets.

The probability that feed particles will exit the rumen is determined primarily by particle size and density (Lechner-Doll et al., 1991). Particle size and specific gravity explained 28 and 59%, respectively, of the variation in retention time of particles in the reticulorumen of sheep (Kaske and Von Englehardt, 1990). Sutherland (1988) described the rumen as an effective first-stage separator. Through filtration and mechanical entanglement, the ruminal digesta mat functions to retain potentially escapable fiber particles, thereby increasing the time for digestion. Welch (1982) proposed that the consistency of the digesta mat would either promote or retard the presentation of fine particles to the reticulo-omasal orifice. Ruminal mat consistency was measured by the rate and distance ascended by a weighted object when subjected to pull by another object three times its weight. Table 14 shows the total distance traveled in 120 s and the rate of ascension (cm/s) of a 454-g weight from the floor of the rumen. Distance traveled during the first 120 s was highest for the 45% forage replacement diet compared with 0 or 15% replacement indicating the presence of relatively more liquid and less mat for the cows fed the 45% replacement diet. The total distance traveled and the rate of ascension increased with increasing replacement of forage with CMP. The rate of ascension of the weight through the digesta mat during 120 s for the

**Table 14**. Ruminal mat consistency during experiment 2.

| | Forage replacement with CMP[1] (% of DM) | | | | |
|---|---|---|---|---|---|
| Item | 0 | 15 | 30 | 45 | SE |
| Distance traveled,[2] cm | | | | | |
| 10 s | 10.5$^{ab}$ | 7.2$^{c}$ | 9.0$^{bc}$ | 13.0$^{a}$ | 1.1 |
| 120 s | 25.5$^{bc}$ | 23.3$^{c}$ | 28.2$^{ab}$ | 32.7$^{a}$ | 2.6 |
| Ascension rate, cm/s | | | | | |
| 10 s | 1.05$^{ab}$ | 0.72$^{c}$ | 0.90$^{bc}$ | 1.30$^{a}$ | 0.10 |
| 120 s | 0.15$^{b}$ | 0.19$^{b}$ | 0.23$^{ab}$ | 0.26$^{a}$ | 0.02 |

[a,b,c]Means within a row with unlike superscripts differ ($P < 0.10$).

[1]CMP = Wet corn milling feed product.

[2]For distance traveled and ascension rate, a lower number indicates a thicker ruminal digesta mat.

15% forage replacement diet was not different from the control diet. These values for ascension rate compare favorably to rates observed when feeding high amounts of WCGF (0.19 to 0.28 cm/s; Allen and Grant, 2000) or soybean hulls (0.15 to 0.18 cm/s; Weidner and Grant, 1994).

In conclusion, for experiment 2, the CMP product has the potential to replace up to 45% of the forage for lactating dairy cows fed diets in which CMP has already replaced 100% of the concentrate. At the 45% replacement level, milk fat percentage was depressed and rumination was reduced slightly, but production of milk fat and efficiency of milk fat production were unchanged. This level of forage replacement for the control diet (which already contained 100% CMP in place of concentrate) amounts to 69.6% of the diet, which is far greater than previous studies have reported (Armentano and Dentine, 1988; Gunderson et al., 1988; Staples et al., 1984; VanBaale et al., 2000).

## Experiment 3

***Dietary composition.*** The control diet contained 50.8% forage and no CMP; the test diet contained 40% CMP in the total ration DM (50% replacement of concentrate plus 30% replacement of forage). The 40% replacement level was selected as optimal because 1) the 50% concentrate replacement level (experiment 1) resulted in a significant increase in efficiency of FCM production and higher levels of replacement did not further increase the efficiency, and 2) milk fat percentage was significantly lower for the 45% forage replacement diet versus the control diet and the 30% replacement diet was the highest level of forage replacement without reduction in milk fat relative to control (experiment 2).

Both diets supplied between 5.7% (control) and 9.5% (CMP diet) excess metabolizable protein (Table 3). The AA balance (g/d) calculated by the CNCPM (1994) indicated that all diets supplied at least 110% of the requirement for each AA. The NDF content of the diets were 27.5% for the control and 35.0% for the CMP diet. In contrast, the nonfiber carbohydrate content was 43.6% for the control and 35.1% for the CMP diet. The CMP diet contained 42% less long particles (greater than 19 mm) than the control diet.

***Feed intake and milk production.*** Cows fed a diet containing 40% CMP from 1 to 63 DIM consumed less DM and more NDF (Table 15), produced more milk, milk fat, and milk protein, and had a greater efficiency of FCM production than cows fed the control diet (Table 16). There were no differences between the two diets in BW, BCS, or net energy balance.

In experiment 1, cows fed the 50% concentrate replacement diet showed a 15% improvement in efficiency of FCM production. In experiment 2, cows fed the 30% forage replacement diet had similar efficiency of FCM production as control, slightly depressed milk fat, but greater total tract digestibility of NDF. In combining these two treatments into one diet, we were able to elicit a 21% improvement in efficiency of FCM production which likely reflected the response of multi- and primiparous cows to optimal concentrate replacement plus increased NDF digestibility from replacement of forage with CMP, but still with adequate dietary effective NDF. The CMP diet resulted in better early lactation performance than a conventional diet. The CMP appears to be an excellent source of digestible NDF for high-producing

**Table 15**. Consumption of DM, protein, and NDF by cows fed experimental diets (experiment 3).

| Item | Control | CMP[1] | SE |
|---|---|---|---|
| DMI | | | |
| kg/d | 26.2[a] | 24.9[b] | 1.1 |
| % of BW | 4.27[a] | 4.06[b] | 0.10 |
| CP intake | | | |
| kg/d | 4.7 | 4.6 | 0.5 |
| % of BW | 0.77 | 0.75 | 0.08 |
| RUP intake | | | |
| kg/d | 1.6 | 1.6 | 0.1 |
| % of BW | 0.26 | 0.26 | 0.01 |
| NDF intake | | | |
| kg/d | 7.1[b] | 8.7[a] | 0.4 |
| % of BW | 1.16[b] | 1.40[a] | 0.05 |

[a,b]Means within a row with unlike superscripts differ ($P < 0.05$).
[1]Wet corn milling feed product.

**Table 16**. Milk production and composition, BW, and body condition as influenced by diet (experiment 3).

| Item | Control | CMP[1] | SE |
|---|---|---|---|
| Milk, kg/d | 38.6[b] | 43.9[a] | 1.6 |
| Milk fat | | | |
| % | 3.99 | 4.11 | 0.10 |
| kg/d | 1.55[b] | 1.81[a] | 0.08 |
| Milk protein | | | |
| % | 3.41 | 3.42 | 0.04 |
| kg/d | 1.32[b] | 1.51[a] | 0.05 |
| Milk lactose | | | |
| % | 4.76 | 4.79 | 0.03 |
| kg/d | 1.83[b] | 2.12[a] | 0.06 |
| 4% FCM, kg/d | 38.5[b] | 44.6[a] | 1.0 |
| FCM/DMI, kg/kg | 1.47[b] | 1.79[a] | 0.08 |
| Average BW, kg | 613 | 612 | 10 |
| BCS[2] | 2.93 | 3.00 | 0.05 |
| BCS change, wk 1 to 9 | 0.05 | 0.12 | 0.04 |
| NEB,[3] Mcal/d | 10.8 | 7.9 | 1.5 |

[a,b]Means within a row with unlike superscripts differ ($P < 0.05$).
[1]Wet corn milling feed product.
[2]Body condition score (1 = thin to 5 = obese; Wildman et al., 1982).
[3]Net energy balance ($NE_{intake} - NE_{maintenance} - NE_{milk}$).

cows immediately postpartum through peak milk production.

## CONCLUSIONS

These series of experiments demonstrate that a properly formulated WCGF product can replace up to 100% of the concentrate and at least 45% of the forage in diets for lactating dairy cows containing 54% forage. These replacement levels translate into nearly 70% of the total ration DM, which is substantially more than suggested by earlier research. An optimal combination for early lactation cows appears to be 50% replacement of concentrate and 30% replacement of forage. This CMP has the potential to result in rations that are economical and capitalize on an abundantly available byproduct feed, particularly in situations in which grains or high quality forage are expensive or limited.

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