# Effects of Nonstructural Carbohydrates and Source of Cereal Grain in High Concentrate Diets of Dairy Cows

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## ABSTRACT

Five primiparous and 5 multiparous Holstein cows were used in an experiment with a double 5 × 5 Latin square design to evaluate the effects of lowering the concentration of nonstructural carbohydrates in high grain diets on intake, chewing activities, digestibility, and yield and composition of milk. Cows received diets consisting of 30% barley silage (dry matter basis) and one of five isocaloric concentrates containing corn, hull-less barley, or barley, ranging in the percentage of nonstructural carbohydrates from 24 to 42%.

Diet did not affect the dry matter intake (DMI) of primiparous cows. However, for multiparous cows, as the concentration of nonstructural carbohydrates in the corn diets was lowered from 34 to 30%, DMI increased from 16.3 to 18.9 kg/d (2.66 to 3.07% of body weight), and, as the concentration of nonstructural carbohydrates in the barley diets was lowered from 29 to 22%, DMI increased from 19.6 to 21.0 kg/d (3.09 to 3.19% of body weight). For both groups of cows, a reduction in the nonstructural carbohydrates in either the corn or barley diets had minimal effects on milk yield, fat-corrected milk yield, fat content, and protein content, except that the fat content of milk from younger cows fed barley diets was lowered (2.70% vs. 2.30%). For diets formulated at similar concentrations of nonstructural carbohydrates, grain source had no effect on DMI or digestible DMI, but milk yield was lower for cows fed the diet containing hull-less barley (25.2 kg/d) than for cows fed the diets containing corn (26.8 kg/d) or barley (28.1 kg/d). When the concentrations of nonstructural carbohydrates in high grain diets were reduced, feed intake was enhanced, but the relationship between the concentration of nonstructural carbohydrates and performance was not consistent. Differences in ruminal availability of carbohydrates need to be accounted for when diets are formulated on the basis of nonstructural carbohydrates using a range of cereal grains.
( **Key words**: barley, corn, hull-less barley, nonstructural carbohydrates)

**Abbreviation key**: **HC** = high concentration of NSC in a corn concentrate, **LB** = low concentration of NSC in a barley concentrate, **MB** = medium concentration of NSC in a barley concentrate, **MC** = medium concentration of NSC in a corn concentrate, **MHB** = medium concentration of NSC in a hull-less barley concentrate, **NSC** = nonstructural carbohydrate, **RDS** = ruminally degradable starch.

## INTRODUCTION

Carbohydrates comprise 70 to 80% of dairy cow diets and provide most of the energy precursors needed for high milk yield (19). For the purpose of diet formulation, carbohydrates are often considered as nonstructural carbohydrates (**NSC**), which are mainly starch and soluble sugars, or structural carbohydrates, which represent cell-wall components that vary widely in digestibility. The NRC (18) does not provide recommendations for the percentage of NSC in dairy cow diets because information is limited on optimal NSC concentrations for diets containing a broad range of feedstuffs.

Based on a limited number of studies, Nocek and Russell (19) observed that milk yield was maximal for diets containing 40% NSC, although some studies (8, 11) reported no effects of NSC concentration on milk yield. Part of the variable response to NSC concentrations might have been due to the sources of NSC used, because cereal grains differ in ruminal availability. Barley is more extensively degraded in the rumen than is corn (20, 28); thus, it is reasonable to expect that the effects of altering concentrations of NSC may differ for diets based on barley and corn.

Nocek and Russell (19) have suggested that the interaction between NSC and dietary fiber is important and have proposed an optimal ratio of NSC to NDF of 0.9 to 1.2. The NSC are rapidly fermented in the rumen, causing low ruminal fluid pH, decreased

Received April 29, 1996.
Accepted January 10, 1997.
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cellulolytic activity, and a depressed ratio of acetate to propionate; therefore, sufficient dietary fiber is necessary to avoid milk fat depression and maintain health (18). This recommended ratio (19) of NSC to NDF equates to 36 to 48% NDF, which is considerably higher than the minimum of 25 to 28% NDF that has been recommended by the NRC (18). For diets that are formulated to provide minimum fiber concentrations, it is uncertain whether the concentration of NSC should also be reduced. Feng et al. (12) reported that, for diets providing low concentrations of NDF from forage sources, lowering NSC from 39 to 29% increased milk yield, microbial yield, and ruminal turnover rate. In practical feeding situations, dietary NSC is often adjusted by changing the ratio of forage to concentrate, thereby confounding the effects of NSC and forage fiber in the diet. Only a few studies have examined the effects of altering NSC concentration without changing the amount of forage fiber in the diet. Coomer et al. (8) and Elliott et al. (11) reported no effect on milk yield and composition for diets ranging from 28 to 38% NSC; however, Sarwar et al. (21) reported that decreasing NSC from 35 to 25% by substituting soybeans and soybean hulls for corn grain increased milk and FCM yields.

The objective of this experiment was to evaluate the effects of altering the concentration of NSC in diets of barley or corn without altering the proportion of forage in the diet on intake, chewing activities, digestive function, and yield and composition of milk. A secondary objective was to evaluate hull-less barley relative to corn and barley in diets formulated to supply similar amounts of energy, NDF from forage, and NSC. The recent availability of hull-less barley cultivars, cultivars from which hulls are spontaneously removed during harvesting, may offer some unique opportunities in the formulation of the diets of dairy cows because hull-less barley cultivars contain more CP, more starch, and less NDF than does hulled barley (10). However, information on the nutritional value of hull-less barley in the diets of dairy cows is limited (W. Z. Yang, K. A. Beauchemin, B. I. Farr, and L. M. Rode, 1996, unpublished data).

## MATERIALS AND METHODS

### Cows and Diets

The experiment was designed as a double 5 × 5 Latin square balanced for residual effects of diets; rows (cows) and periods were blocking factors. Five lactating primiparous Holstein cows that averaged 59 DIM (SD = 11) at the start of the experiment were used in square 1, and 5 multiparous cows fitted with ruminal cannulas that averaged 53 DIM (SD = 19) were used in square 2. Cows in square 2 started the experiment about 2 mo later than did cows in square 1.

Cows received one of five low fiber diets consisting of 30% barley silage and 70% concentrate (DM basis) during each 21-d experimental period. Thus, all diets contained about 18% NDF from forage. The barley silage was harvested in the mid-dough stage with a 0.95-cm theoretical chop length and a 0.99-cm geometric mean particle length, which was determined by wet-sieving and calculated without the soluble fraction as was described previously (4). Five concentrates that varied in percentage of NSC, but had similar $NE_L$ contents, were formulated using corn, hull-less barley, or barley (Table 1). Concentrates were 1) high NSC in a corn concentrate (**HC**), 2) medium NSC in a corn concentrate (**MC**), 3) medium NSC in a hull-less barley (Condor cultivar) concentrate (**MHB**), 4) medium NSC in a barley concentrate (**MB**), and 5) low NSC in a barley concentrate (**LB**). The diet containing HC contained about 42% NSC; MC, MHB, and MB diets contained about 35% NSC; and the LB diet contained about 24% NSC. The range in NSC percentages at similar $NE_L$ values was attained by replacing some of the cereal grain with ground oat hulls and canola oil. The diets also met or exceeded NRC (18) requirements for CP, RUP, minerals, and vitamins (Table 2).

Cows were fed for ad libitum intake throughout the experiment. They were permitted continuous access to silage, which was allocated three times daily, except when concentrate was fed. Concentrate was allocated in equal portions during two 1-h feeding periods daily, although concentrate remaining after the evening feeding was reallocated the next morning. The amount of concentrate allocated was adjusted on a regular basis to maintain the desired ratio of forage to concentrate. Concentrate and silage orts were removed before the evening feeding, weighed, composited weekly, subsampled, and retained for chemical analysis to determine DMI and NDF intake.

Cows were cared for according to the Canadian Council on Animal Care guidelines (Ottawa, ON). Cows were housed in stalls bedded with wood shavings; cows were turned outside for 1 to 2 h daily except on days when chewing activities were recorded. Cows were milked in their stalls twice daily. Milk yield was recorded on the last 8 d of each period. Morning and evening milk was sampled on 2 d during this period, and mean daily fat, protein, and lactose contents, weighted for yield, were calculated. Milk yield on these 2 d was used to calculate 4% FCM and SCM. Milk components were determined by the Alberta Agriculture, Food and Rural Development Milk Testing Laboratory (Edmonton, AB, Canada).

Feed efficiency was calculated as the ratio of energy outputs (maintenance, BW change, and milk) to $NE_L$ consumed as described previously (3). Energy of maintenance was calculated as $BW^{0.75}$ (kilograms) × 0.08 (megacalories per $kilogram^{0.75}$); BW change was assumed to be 5.12 Mcal/kg of gain or 4.92 Mcal/kg of loss; and milk energy was calculated as SCM (kilograms) × 0.75 (megacalories per kilogram).

Chewing activities were monitored for approximately 4 d per period using a strain gauge transducer that was linked to a computerized data acquisition system (6). In addition to computer records, analog signals from the transducers were recorded continuously using a multichannel chart recorder. Computer records were verified with chart tracings to ensure accurate assessment of eating and ruminating activities. Chewing activities were expressed per unit of intake (DM, NDF, and NDF from forage) by dividing minutes or number of chews by mean daily intake for the period.

Each cow was offered, twice daily, 30 g/d of barley containing chromic oxide to supply 1 g/d of Cr. Approximately 16 fecal samples were collected during an 8-d interval to account for variation between days. Sampling times differed each day such that the entire 24-h day was represented to account for possible diurnal variation. Fecal samples were dried (55°C), ground to pass a 1-mm screen, and pooled by period for each cow. Concentrations of Cr were determined using atomic absorption spectrometry (29) to calculate DM digestibility.

## In Sacco Measurements

Three of the multiparous cows were used during the five experimental periods for in sacco measurements. A composite sample of barley silage was dried in a forced-air oven at 55°C and ground to pass a 2-mm screen. Five grams of DM were then weighed

TABLE 1. Composition of concentrate (percentage of DM[1]).[2,3]

| Component | HC | MC | MHB | MB | LB |
|---|---|---|---|---|---|
| Ingredient | | | | | |
| Corn, steam-rolled | 76.74 | 55.03 | ... | ... | ... |
| Hull-less barley, steam-rolled | ... | ... | 80.13 | ... | ... |
| Barley, steam-rolled | ... | ... | ... | 72.11 | 46.99 |
| Corn gluten meal | 6.37 | 5.47 | 3.23 | 3.13 | 2.99 |
| Corn distillers dried grains | ... | ... | 3.17 | 3.17 | 3.02 |
| Blood meal | 6.54 | 5.53 | 3.27 | 3.27 | 3.02 |
| Canola meal | 2.85 | 9.92 | 1.27 | 8.87 | 15.59 |
| Oat hulls, ground | ... | 12.53 | ... | ... | 14.55 |
| Calcium carbonate | 1.33 | 1.32 | 1.47 | 1.49 | 1.38 |
| Dicalcium phosphate | 1.49 | 1.20 | 1.31 | 1.01 | 0.93 |
| Monophosphorus | 0.09 | 0.14 | ... | ... | ... |
| Mineral and vitamin premix[4] | 1.71 | 1.71 | 1.71 | 1.71 | 1.71 |
| Pellet binder | 1.17 | 1.13 | 1.12 | 1.12 | 1.12 |
| Molasses, liquid | 0.57 | 0.57 | 0.57 | 0.57 | 0.56 |
| Canola oil | 1.14 | 5.45 | 2.75 | 3.90 | 8.14 |
| Chemical component | | | | | |
| DM | 87.1 | 89.1 | 89.3 | 87.9 | 89.5 |
| OM | 89.1 | 89.8 | 85.3 | 87.1 | 88.7 |
| CP | 27.4 | 23.1 | 26.8 | 25.2 | 22.3 |
| $NE_L$,[5] Mcal/kg of DM | 1.94 | 1.94 | 1.94 | 1.94 | 1.94 |
| NDF | 17.0 | 24.1 | 18.8 | 22.1 | 36.2 |
| ADF | 5.8 | 11.7 | 8.6 | 10.26 | 16.5 |
| NSC | 41.8 | 36.4 | 35.5 | 34.5 | 24.0 |
| Starch | 38.5 | 28.1 | 27.1 | 25.3 | 20.6 |
| Ether extract | 2.94 | 6.23 | 4.22 | 5.40 | 6.23 |

[1]Excluding DM and $NE_L$.

[2]Diets consisted of 70% concentrate and 30% barley silage (DM basis).

[3]HC = High concentration of nonstructural carbohydrates (NSC) in a corn concentrate, MC = medium concentration of NSC in a corn concentrate, MHB = medium concentration of NSC in a hull-less barley concentrate, MB = medium concentration of NSC in a barley concentrate, and LB = low concentration of NSC in a barley concentrate.

[4]Supplied per kilogram of premix: 166,700 IU of vitamin A, 20,850 IU of vitamin $D_3$, 200 IU of vitamin E, 895 g of NaCl, 5.5 g of Mg, 9.0 g of K, 8.9 g of Zn, 6.75 g of Mn, 1.63 g of Cu, and 28.7 mg of Se.

[5]The $NE_L$ of the concentrate was calculated from NRC (18).

into small bags (10 × 20 cm) made of monofilament Pecap® polyester (pore size, 51 ± 2 μm; B. & S. H. Thompson, Ville Mont-Royal, QC, Canada) and heat-sealed. Large (20 × 30 cm) mesh retaining sacs with 3- × 5-mm pores that permitted ruminal fluid to percolate freely were placed in the rumen of each cow. Individual polyester bags were soaked in warm water for 10 min, and duplicate bags were added to the retaining sacs, representing 3, 6, 9, 12, 24, 36, 48, 72, 96, and 120 h of incubation. All bags were removed at the end of the incubation period, washed under running tap water, and then machine washed until the effluent was clear. Bags were dried at 60°C for 48 h.

Kinetics of DM disappearance in sacco were estimated using nonlinear least squares (PROC NLIN of SAS) (22). For each cow and period, the following model (17) was fitted to the percentage of DM disappearance:

$$y = a + b\,(1 - e^{-c(t - L)}) \text{ for } t > L \qquad [1]$$

where

a = soluble fraction (percentage),
b = slowly digested fraction (percentage),
c = fractional rate of disappearance (percentage per hour),
L = lag time (hours), and
t = time of incubation (hours).

Effective ruminal degradability (ERD) of DM was estimated using the model

$$ERD = a + b \times [c/(c + k)] \times e^{(-k \times L)/100} \qquad [2]$$

where k = rate of particulate passage (assumed to be 3%/h).

## Feed Analysis

Composite samples of all feeds were obtained during each experimental period. Silage was dried to a constant weight in a forced-air oven at 55°C. Analytical DM content of feeds was determined by oven-drying at 135°C; OM was determined by ashing the samples; and CP was determined by the micro-Kjeldahl method (1). The NDF, ADF, and acid detergent lignin (72% $H_2SO_4$) were determined using the nonsequential method described by Van Soest et al. (27). Sodium sulfite was used only in the NDF analysis of the protein supplement, and the NDF values were not corrected for ash content. Starch was determined by the enzymatic method described by Herrera-Saldana et al. (14) as modified by our laboratory. Sample size and reagents were reduced so that samples could be read colorimetrically at 490 nm using a plate reader. The enzymatic hydrolysis was extended to 1 h using α-amylase (Termamyl; Novo

TABLE 2. Composition of diets and barley silage (percentage of DM[1]).

| Item | Diet[2] | | | | | Barley silage |
|---|---|---|---|---|---|---|
| | HC | MC | MHB | MB | LB | |
| Ingredient | | | | | | |
| Concentrate | 70 | 70 | 70 | 70 | 70 | . . . |
| Barley silage | 30 | 30 | 30 | 30 | 30 | . . . |
| Chemical component[3] | | | | | | |
| DM | 73.4 | 74.8 | 74.9 | 74.0 | 75.0 | 41.4 |
| OM | 88.9 | 89.4 | 86.2 | 87.5 | 88.7 | 88.5 |
| CP | 22.1 | 19.1 | 21.7 | 20.6 | 18.5 | 9.8 |
| $NE_L$,[4] Mcal/kg of DM | 1.74 | 1.74 | 1.74 | 1.74 | 1.74 | 1.25 |
| NDF | 29.7 | 34.7 | 31.0 | 33.3 | 43.2 | 59.4 |
| NDF from Forage | 17.8 | 17.8 | 17.8 | 17.8 | 17.8 | 59.4 |
| ADF | 15.7 | 19.8 | 17.6 | 18.8 | 23.1 | 38.7 |
| Acid detergent lignin | . . . | . . . | . . . | . . . | . . . | 5.5 |
| NSC | 34.4 | 30.7 | 30.0 | 29.3 | 22.0 | 17.3 |
| NSC:NDF | 1.2:1 | 0.9:1 | 1.0:1 | 0.9:1 | 0.5:1 | 0.3:1 |
| NSC:NDF from Forage | 1.9:1 | 1.7:1 | 1.7:1 | 1.6:1 | 1.2:1 | 0.3:1 |
| Starch | 30.0 | 22.7 | 22.0 | 20.8 | 17.5 | 10.2 |

[1]Excluding DM and $NE_L$.

[2]HC = High concentration of nonstructural carbohydrates (NSC) in a corn concentrate, MC = medium concentration of NSC in a corn concentrate, MHB = medium concentration of NSC in a hull-less barley concentrate, MB = medium concentration of NSC in a barley concentrate, and LB = low concentration of NSC in a barley concentrate.

[3]Calculated composition based on Table 1.

[4]Estimated $NE_L$ content based on NRC (18).

Nordisk, Bagsvaerd, Denmark), and amyloglucosidase (number 208-469; Boehringer Mannheim, Laval, QC, Canada) was used rather than glucoamylase. Ether extract was determined for each concentrate and for barley silage (1). The NSC was calculated as

$$\text{NSC (percentage)} = 100 - [\text{CP (percentage)} + \text{NDF (percentage)} + \text{ash (percentage)} + \text{ether extract (percentage)}]. \quad [3]$$

The Ca was determined using atomic absorption spectrophotometry, and P was analyzed colorimetrically using an autoanalyzer (1). Concentrations of all nutrients were expressed as a percentage of DM (Tables 1 and 2).

### Statistical Analysis

Data on several variables, including intake, BW, milk, chewing, and digestibility, were analyzed using the general linear models procedure of SAS (22); group, cow within group, period within group, diet, and the interaction of group and diet were terms in the model, which provided 24 degrees of freedom for the error term (24). The effect of group was assumed to be caused by the parity of cows (primiparous vs. multiparous). Least squares means are presented in the text and tables. Single degree of freedom contrasts were used to evaluate the effects of lowering the percentage of NCS in corn (HC vs. MC) and barley (MB vs. LB) diets and to compare hull-less barley to corn (MHB vs. MC) and barley (MHB vs. MB) diets. In the case of a significant interaction of parity and diet, means for diet within parity were compared using the PDIFF option in the PROC GLM of SAS (22). To evaluate the linear and quadratic effects of NSC and starch on milk yield and composition without adjustment for grain source, the effect of diet was removed from the model, and intake of NSC or starch was included as continuous linear (1 df) and quadratic (1 df) variables in the model.

The kinetics of DM disappearance were analyzed using a model that included cow and diet; the error term had eight degrees of freedom. Only when the main effect of diet was significant were the means compared using the PDIFF option of PROC GLM of SAS (22). Significance was declared at $P < 0.05$ unless otherwise noted.

## RESULTS AND DISCUSSION

A supplemental source of fat was necessary to ensure that concentrates differed in NSC but contained the same concentration of $NE_L$. Canola oil was used to compensate for the lower energy contents of barley and hull-less barley compared with corn and to increase the energy content when oat hulls were added to reduce dietary NSC. As expected, fat addition did not depress ruminal fiber digestion, milk protein, or milk fat content of milk. Several protein sources were used rather than a single source to ensure an adequate postruminal supply of amino acids. The amount of each protein source used varied among diets, but the effects of this variation were likely insignificant.

Although NSC content of the concentrates ranged from 24 to 42% (Table 1), NSC concentrations of the total diets ranged from 22 to 34% (Table 2). When the relatively high CP content of these diets (>18.5%) and all mineral and fat additions were considered, the maximum percentage of NSC attained was only 34%. The high NSC concentration used in this study was below 40% NSC, which was suggested as the optimal concentration by Nocek and Russell (19), but was consistent with concentrations in diets based on corn that are typically fed to high yielding dairy cows. In a limited sample of high yielding herds, dietary NSC content averaged 34% and ranged from 32 to 39% (7).

Although the diets contained only 17.8% NDF from forage, only the LB diet had a ratio of NSC to NDF below the range of 0.9 to 1.2 (Table 2), which was the range that had been suggested as the optimal range by Nocek and Russell (19). Formulation of diets on the basis of NSC alters NDF content. Even though NDF from forage remained constant, NDF from concentrate sources increased, causing the total dietary NDF to increase from 29.7 to 43.2% as dietary NSC concentrations decreased from 34 to 22%. For barley diets (2) and corn diets (26), the NDF from concentrate sources has been reported as being about half as effective as NDF from forage in increasing the fat content in milk. Given the difference in effectiveness of NDF from forage and grain sources, it is questionable as to whether the ratio of NSC to NDF is important.

Although DMI was similar for both groups of cows (Table 3), multiparous cows consumed less DM relative to BW than did primiparous cows (3.09 vs. 3.33% of BW). This observation was unexpected and may suggest that the effects of low fiber diets on intake differed for younger and older cows. The interaction of parity and diet was also significant; diet affected DMI (kilograms per day and percentage of BW) of multiparous cows, but did not affect DMI of primiparous cows. The results for older cows supported the theory that a reduction in the NSC content of high grain diets was beneficial because high NSC concentrations depressed intake (9). However, NSC percentages that negatively affected DMI were apparently higher for younger cows than for older cows. For older cows, a lower percentage of NSC increased DMI of corn diets from 16.3 to 18.9 kg/d (2.66 to 3.07% of BW) and increased DMI of barley diets from 19.6 to 21.0 kg/d (3.09 to 3.19% of BW), although the increase for barley was not significant ($P > 0.10$).

As a result of differences in DMI, the actual amount of NSC that was consumed by cows fed HC or MC was similar ($P > 0.05$), even though the concentration of NSC in the diet differed. In contrast, reduced NSC in barley diets (MB vs. LB) decreased intake of NSC. For the barley and corn diets, the lower NSC concentration reduced the intake of starch; cows fed MC consumed less starch than did cows fed HC, and cows fed LB consumed less starch than did cows fed MB. Because the diets were isocaloric, energy intake followed a pattern similar to that for DMI.

Digestibility of DM was similar for primiparous and multiparous cows (69.1% vs. 68.4%), but effects of diet on digestibility differed for these two groups. For younger cows, the lowering of NSC content of barley and corn diets decreased DM digestibility as expected. For older cows, DM digestibility was only decreased when the MB diet was compared with the LB diet.

For diets formulated to supply similar percentages of NSC (MC, MHB, and MB diets), grain source had no effect ($P > 0.10$) on DMI (kilograms per day or percentage of BW), digestible DMI, or intakes of $NE_L$ and starch. However, DM digestibility of the MHB diet was similar to the DM digestibility of the MB diet but higher than that of the MC diet.

Milk yield of primiparous and multiparous cows was similar (26.2 vs. 27.1 kg/d; $P > 0.10$), and diet affected the milk yield of cows in both groups similarly (Table 4). As the NSC content was reduced from the HC diet to the MC diet and from the MB diet to the LB diet, yields of milk, FCM, and milk components were not affected ($P > 0.10$). Linear and quadratic relationships between NSC intake and milk or FCM yield, examined across diets, were not significant. In addition, feed efficiency, calculated as the ratio of $NE_L$ outputs to $NE_L$ consumed, was not improved as the percentage of NSC in corn or barley diets decreased. For both groups of cows, feed efficiency was higher for cows fed the MB diet than for cows fed the LB diet and was similar for cows fed the HC and MC diets.

In other studies in which NDF from forage was maintained at a relatively constant level, but at higher amounts than were used in this study, the response of milk yield to decreased dietary NSC has been variable. For diets ranging between 28 and 38% NSC, Coomer et al. (8) and Elliott et al. (11)

TABLE 3. Effects of dietary nonstructural carbohydrates (NSC) on BW and nutrient intake means.[1]

| | Primiparous cows | | | | | Multiparous cows | | | | | | $P^2$ | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | HC | MC | MHB | MB | LB | HC | MC | MHB | MB | LB | SE | P | D | P × D | HC vs. MC | MB vs. LB | MHB vs. MC | MHB vs. MB |
| BW, kg | 547 | 548 | 548 | 553 | 549 | 606 | 615 | 615 | 619 | 620 | 7 | *** | NS[3] | NS | NS | NS | NS | NS |
| BW Change, kg/d | –0.05 | 0.61 | 0.17 | 0.74 | 0.05 | –0.50 | 0.30 | –0.16 | 0.52 | –0.38 | 0.33 | NS | * | NS | * | * | NS | † |
| DMI, % of BW | 3.39 | 3.35 | 3.37 | 3.23 | 3.30 | 2.66[b] | 3.07[a] | 3.09[a] | 3.19[a] | 3.42[a] | 0.12 | ** | NS | * | NS | NS | NS | NS |
| DMI, kg/d | 18.5 | 18.4 | 18.4 | 17.7 | 18.0 | 16.3[b] | 18.9[a] | 18.9[a] | 19.6[a] | 21.0[a] | 0.8 | NS | NS | * | NS | NS | NS | NS |
| Digestible DMI, kg/d | 13.1[ab] | 12.3[ab] | 13.7[a] | 12.6[ab] | 11.2[b] | 10.8[b] | 12.6[ab] | 13.6[a] | 14.2[a] | 14.1[a] | 0.7 | NS | NS | * | NS | NS | † | NS |
| DM Digestibility, % | 70.8[ab] | 67.1[b] | 74.7[a] | 71.2[ab] | 62.0[c] | 64.7[b] | 65.9[b] | 72.1[a] | 72.0[a] | 67.1[b] | 1.7 | NS | *** | * | NS | *** | *** | NS |
| Concentrate, % of DMI | 68.8 | 68.4 | 69.5 | 68.5 | 68.3 | 66.2 | 68.4 | 72.4 | 71.2 | 69.7 | 1.8 | NS | NS | NS | NS | NS | NS | NS |
| $NE_L$ Intake, Mcal/d | 32.0 | 31.7 | 31.8 | 30.6 | 31.1 | 28.1[b] | 32.5[a] | 33.0[a] | 34.2[a] | 36.5[a] | 1.4 | NS | NS | * | NS | NS | NS | NS |
| NSC Intake, kg/d | 6.3[a] | 5.6[ab] | 5.5[b] | 5.2[b] | 3.9[c] | 5.5[a] | 5.7[a] | 5.7[a] | 5.8[a] | 4.6[b] | 0.3 | NS | *** | † | NS | NS | NS | NS |
| Starch intake, kg/d | 5.5[a] | 4.1[b] | 4.0[b] | 3.6[bc] | 3.1[c] | 4.8[a] | 4.2[b] | 4.2[ab] | 4.1[b] | 3.7[b] | 0.2 | NS | *** | † | *** | * | NS | NS |

[a,b,c]Means with different superscripts for diets within parity differ ($P < 0.05$).

[1]HC = High concentration of NSC in a corn concentrate, MC = medium concentration of NSC in a corn concentrate, MHB = medium concentration of NSC in a hull-less barley concentrate, MB = medium concentration of NSC in a barley concentrate, and LB = low concentration of NSC in a barley concentrate.

[2]P = Effect of parity; D = main effect of diet.

[3]$P > 0.10$.

†$P < 0.10$.

*$P < 0.05$.

**$P < 0.01$.

***$P < 0.001$.

reported no effect ($P > 0.05$) of percentage of NSC on yield of milk or FCM; however, Sarwar et al. (21) decreased NSC from 35 to 25%, and yields of milk and FCM increased ($P < 0.10$). Using low fiber diets, Feng et al. (12) decreased the percentage of NSC from 39 to 29% and reported increased yields of milk and FCM, but this response might have been related to changes in the concentration of NDF from forage, which ranged from 0 to 23.9%.

For diets that were formulated to supply similar percentages of NSC (MC, MHB, and MB diets), milk yield was similar for cows fed the MC and MB diets, confirming the study by Grings et al. (13), but milk yield tended to be lower ($P < 0.10$) for cows fed the MHB diet. Similarly, cows fed the MHB diet had lower feed efficiency than did cows fed the other diets. Because little information has been published on the use of hull-less barley for dairy cows, we assumed that its $NE_L$ content was greater than that of barley (1.99 vs. 1.92 Mcal/kg of DM). Edney et al. (10) reported that starch content of hull-less barley was higher than that of barley and was similar to that of wheat because of the absence of hulls. However, the lower milk yield and lower feed efficiency of cows fed the MHB diet compared with those of cows fed the MB diet indicated that $NE_L$ was overestimated. The only other published study, to our knowledge, using hull-less barley in dairy cow diets (W. Z. Yang, K. A. Beauchemin, B. I. Farr, and L. M. Rode, 1996, unpublished data) reported similar milk yield and composition for diets containing 60% concentrate consisting of either hull-less barley (cultivar, Condor), barley, or corn. The hull-less barley diet used in that study was assumed to contain more $NE_L$ than the barley diet, but no advantage was gained by using hull-less barley compared with barley. In that study, ruminal and total tract DM digestibilities were lower than expected for diets containing hull-less barley. The researchers speculated that the degree of processing used was insufficient for hull-less barley; bulk density of barley was reduced to 68% of whole barley by steam-rolling; whereas, bulk density of hull-less barley was 89% of whole barley (W. Z. Yang, 1996, personal communication). The grains used in our study were processed in a similar manner, and the lower than expected milk yield for cows fed hull-less barley was possibly caused by ineffective grain processing.

TABLE 4. Effects of dietary nonstructural carbohydrates (NSC) on milk yield and milk composition.[1]

| | Primiparous cows | | | | | Multiparous cows | | | | | | P[2] | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | HC | MC | MHB | MB | LB | HC | MC | MHB | MB | LB | SE | P | D | P × D | HC vs. MC | MB vs. LB | MHB vs. MC | MHB vs. MB |
| Yield, kg/d | | | | | | | | | | | | | | | | | | |
| Milk | 26.0 | 26.3 | 25.5 | 26.8 | 26.4 | 25.3 | 27.2 | 24.9 | 29.3 | 28.8 | 0.9 | NS[3] | * | NS | NS | NS | † | ** |
| 4% FCM | 21.8 | 21.2 | 21.9 | 21.6 | 19.8 | 21.9[bc] | 23.5[abc] | 21.6[c] | 24.2[ab] | 25.1[a] | 0.9 | ** | NS | * | NS | NS | NS | NS |
| SCM | 22.4 | 21.9 | 22.8 | 22.7 | 21.2 | 21.4[b] | 23.1[ab] | 21.3[b] | 24.3[a] | 25.0[a] | 0.9 | NS | NS | * | NS | NS | NS | NS |
| Fat | 0.76[a] | 0.71[ab] | 0.76[a] | 0.72[ab] | 0.61[b] | 0.78[ab] | 0.83[ab] | 0.77[b] | 0.84[ab] | 0.89[a] | 0.04 | *** | NS | * | NS | NS | NS | NS |
| Protein | 0.81 | 0.81 | 0.84 | 0.87 | 0.86 | 0.73 | 0.79 | 0.75 | 0.86 | 0.86 | 0.03 | † | * | NS | NS | NS | NS | * |
| Lactose | 1.31 | 1.31 | 1.32 | 1.36 | 1.34 | 1.19 | 1.29 | 1.17 | 1.39 | 1.40 | 0.05 | NS | * | NS | NS | NS | NS | * |
| Composition, % | | | | | | | | | | | | | | | | | | |
| Fat | 2.95[a] | 2.79[a] | 2.96[a] | 2.70[a] | 2.30[b] | 3.24 | 3.13 | 3.08 | 2.97 | 3.13 | 0.13 | *** | * | † | NS | NS | NS | NS |
| Protein | 3.13 | 3.11 | 3.20 | 3.22 | 3.20 | 2.86 | 2.91 | 3.02 | 3.02 | 2.96 | 0.05 | *** | * | NS | NS | NS | * | NS |
| Lactose | 5.01 | 5.00 | 5.04 | 5.04 | 5.03 | 4.65 | 4.69 | 4.67 | 4.79 | 4.78 | 0.04 | *** | NS | NS | NS | NS | NS | NS |
| Efficiency[4] | 0.80 | 0.91 | 0.85 | 0.98 | 0.81 | 0.84 | 0.88 | 0.74 | 0.89 | 0.74 | 0.05 | † | ** | NS | NS | ** | * | ** |

[a,b,c]Means with different superscripts for diets within parity differ ($P < 0.05$).

[1]HC = High concentration of NSC in a corn concentrate, MC = medium concentration of NSC in a corn concentrate, MHB = medium concentration of NSC in a hull-less barley concentrate, MB = medium concentration of NSC in a barley concentrate, and LB = low concentration of NSC in a barley concentrate.

[2]P = Effect of parity; D = main effect of diet.

[3]$P > 0.10$.

[4]Feed efficiency was calculated as the ratio of energy outputs (maintenance, BW change, and milk) to $NE_L$ consumed (3).

[†]$P < 0.10$.

*$P < 0.05$.

**$P < 0.01$.

***$P < 0.001$.

Diet had minimal effects on milk composition (Table 4). A reduction in the NSC content of corn and barley diets had no effect on milk lactose or protein content, although protein content was lower for primiparous cows than for multiparous cows (2.74% vs. 3.11%). Diet did not affect milk fat percentage for multiparous cows, but, for primiparous cows, milk fat content was lower for cows fed the LB diet than for cows fed the other diets. Thus, the effects of lowered NSC content of diets on fat content of milk were limited to MB and LB and only for primiparous cows; linear and quadratic effects of NSC intake on milk fat content were not statistically significant when combined over the five diets, even after adjustment for the effects of group, cow, and period.

Sutton et al. (25) concluded that, for dairy cows fed high concentrate diets, lowering the ratio of starch to NDF from 2 to 1 to 1 to 1 by substituting cereal grains with by-product feeds resulted in a decline in milk yield but an increase in fat yield. In our study, decreasing NSC concentrations lowered the ratio of starch to NDF in the diets from 1 to 1 to 0.4 to 1; however, the effects on milk fat were the opposite of those reported by others after similar changes in ratios of starch to fiber (2, 25, 26). Part of the reason for this difference might have been that the $NE_L$ content of the diets was constant in our study but not in some of the other studies (2, 26). Additionally, the oat hulls used were ground and, therefore, were not an effective fiber source.

Milk fat content was not affected by cereal grain when diets were formulated to contain similar $NE_L$ and NSC contents. However, milk protein content was higher for cows fed the MHB diet than for cows fed the MC diet (3.11% vs. 3.01%); no difference was found between MHB and MB diets (3.11% vs. 3.12%; $P > 0.05$). Milk protein was higher for cows fed barley diets (hulled and hull-less) than for cows fed corn diets, which might have resulted from an increase in microbial yield caused by higher ruminal availability of carbohydrates. Higher microbial protein yield for cows fed barley diets than for cows fed corn diets is well documented (16, 23). Alternatively, differences in milk protein might have resulted from the variation among diets in the amount and source of protein supplements. Differences caused by protein source are unlikely, however, because diets were formulated in excess of CP requirements and exceeded recommendations for RUP (18).

TABLE 5. Effects of dietary nonstructural carbohydrates (NSC) on time spent chewing and number of chews.[1]

| | | | | | | | | | | | | $P$[2,3] | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Primiparous cows | | | | | Multiparous cows | | | | | | | | HC vs. | MB vs. | MHB vs. | MHB vs. |
| Item | HC | MC | MHB | MB | LB | HC | MC | MHB | MB | LB | SE | P | D | MC | LB | MC | MB |
| Eating | | | | | | | | | | | | | | | | | |
| min/d | 264 | 256 | 257 | 245 | 264 | 346 | 326 | 302 | 316 | 346 | 17 | *** | NS | NS | NS | NS | NS |
| Ruminating | | | | | | | | | | | | | | | | | |
| min/d | 439 | 468 | 450 | 491 | 484 | 429 | 443 | 437 | 500 | 462 | 22 | NS | † | NS | NS | NS | * |
| Chews/d (×10[3]) | 28.3 | 29.6 | 28.8 | 31.3 | 30.7 | 26.8 | 28.1 | 27.3 | 32.4 | 28.3 | 1.6 | NS | NS | NS | † | NS | * |
| Rumination periods | | | | | | | | | | | | | | | | | |
| Periods/d | 16.5 | 15.0 | 14.9 | 15.6 | 15.0 | 16.0 | 14.3 | 15.8 | 16.0 | 15.5 | 0.5 | NS | † | ** | NS | NS | NS |
| Duration | 27.9 | 31.7 | 31.1 | 32.4 | 32.6 | 26.9 | 30.9 | 27.9 | 31.5 | 30.2 | 1.4 | † | * | * | NS | NS | † |
| Rumination boluses | | | | | | | | | | | | | | | | | |
| Boluses per period | 27.9 | 31.1 | 31.3 | 32.0 | 31.6 | 27.8 | 31.6 | 28.6 | 31.4 | 31.5 | 1.5 | NS | † | * | NS | NS | NS |
| Duration of boluses, s | 57.2 | 59.5 | 57.1 | 59.5 | 59.2 | 56.3 | 57.6 | 57.8 | 58.4 | 56.5 | 1.7 | NS | NS | NS | NS | NS | NS |
| Chews per bolus | 64.1 | 65.6 | 63.7 | 64.4 | 66.1 | 61.5 | 63.2 | 63.1 | 65.6 | 60.8 | 2.1 | NS | NS | NS | NS | NS | NS |

[1]HC = High concentration of NSC in a corn concentrate, MC = medium concentration of NSC in a corn concentrate, MHB = medium concentration of NSC in a hull-less barley concentrate, MB = medium concentration of NSC in a barley concentrate, and LB = low concentration of NSC in a barley concentrate.

[2]P = Effect of parity; D = main effect of diet.

[3]Interactions of parity and diet were nonsignificant ($P > 0.10$), excluding rumination time (minutes per kilogram of DM) for which $P = 0.06$.

†$P < 0.10$.

*$P < 0.05$.

**$P < 0.01$.

***$P < 0.001$.

Despite the minimal amount of NDF from forage in these diets, total chewing time (eating and ruminating) exceeded 11 h/d (Table 5). Eating time averaged 4.3 h/d for primiparous cows and 5.5 h/d for multiparous cows; however, there was no effect of diet ($P > 0.10$). These estimates were similar to eating times reported previously for high grain diets that derived similar concentrations of NDF from forage (3).

Rumination time was similar for primiparous and multiparous cows and averaged about 7.7 h/d; some differences were caused by diet ($P < 0.10$). Rumination time was similar for cows fed the MHB and MC diets (444 vs. 456 min/d; $P > 0.05$), but cows fed the MHB diet ruminated less than did those fed the MB diet (444 vs. 496 min/d), indicating that barley hulls promoted rumination. The greater rumination time by cows fed the MB diet than that of cows fed the MHB diet corresponded to more rumination chews, longer rumination periods, and more ruminated boluses each day, but the characteristics of individual boluses were similar for cows fed either diet. Greater rumination activity of cows fed barley was apparently due to a higher intake of NDF in the form of intact kernels and hulls. Hulls are high in fiber (>70% NDF) and represent about 15 to 20% of the total grain. When the hulls remain intact before feeding, they are regurgitated and remasticated during rumination (5), but grinding of hulls before feeding reduces this effect.

Increased rumination by cows fed barley was apparently not due to depressed fiber digestion, which is associated with low ruminal pH, as was suggested by Beauchemin et al. (3), because ruminal digestion kinetics of barley silage were similar for barley and corn diets (Table 6). We hypothesized that lowering the NSC content of the diet might have increased the ruminal digestibility of barley silage, because fiber digestion usually decreased when starch was added to diets (9). However, the kinetics of in sacco digestion of barley silage showed only minor effects of diet, albeit statistically significant differences for rate of disappearance. These differences in rate, however, did not affect the effective ruminal degradability of silage ($P > 0.05$).

Although NSC are considered to be either soluble or rapidly fermentable in the rumen, not all of the components of NSC are fermented in the same manner. Starch content of ingredients is quite variable, reportedly ranging between 63 and 78% for corn and between 52 to 74% for barley (14, 28). For the diets used in our study, between 71 and 87% of the NSC was starch; the remainder was attributed to sugars, pectins, soluble lignin, and other neutral detergent soluble carbohydrates (27). Although intake of starch varied among diets, linear and quadratic effects of starch intake on milk yield, FCM, SCM, and yield and percentage of milk components were not significant after adjustments for the effects of group, cow, and period.

Concentration of NSC or starch does not account for differences in ruminal digestibility (20). Corn starch was digested in the rumen much more slowly than was barley starch because of differences in the structure of these two cereal grains (15). To quantify these differences, the intake of ruminal degradable starch (**RDS**) was calculated using the values given by Nocek and Tamminga (20). Additionally, RDS of rolled hull-less barley was assumed to be the same as

TABLE 6. Effects of dietary nonstructural carbohydrates (NSC) on ruminal digestion kinetics of barley silage DM.[1]

| | Diet[2] | | | | | |
|---|---|---|---|---|---|---|
| Item | HC | MC | MHB | MB | LB | SE |
| Soluble fraction, % | 33.3 | 34.5 | 34.8 | 33.7 | 35.2 | 1.6 |
| Slowly digested fraction, % | 33.2 | 36.6 | 40.1 | 33.8 | 32.9 | 2.4 |
| Extent of disappearance,[3] % | 66.5 | 71.1 | 74.9 | 67.5 | 68.1 | 3.1 |
| Rate of disappearance, %/h | 4.27[a] | 2.97[ab] | 2.29[b] | 3.04[ab] | 3.14[ab] | 0.5 |
| Lag, h | 0 | 0 | 0 | 0 | 0 | . . . |
| ERD,[4] % | 52.6 | 52.4 | 50.8 | 50.3 | 51.4 | 1.0 |

[a,b]Means for diets within a row differ ($P < 0.05$).

[1]Determined in multiparous cows.

[2]HC = High concentration of NSC in a corn concentrate, MC = medium concentration of NSC in a corn concentrate, MHB = medium concentration of NSC in a hull-less barley concentrate, MB = medium concentration of NSC in a barley concentrate, and LB = low concentration of NSC in a barley concentrate.

[3]Sum of the soluble and slowly digested fractions.

[4]Effective ruminal degradability.

that for rolled barley, and a value of 50% was assumed for RDS of barley silage. After adjustment for effects of parity, cow, and period, a significant curvilinear relationship was observed between RDS intake and milk yield: milk yield (kilograms per day) = –5.59 + 23.37 × RDS (kilograms per day) – 4.31 × $RDS^2$ (kilograms per day); the linear (L) and quadratic (Q) regression coefficients of this equation were significantly different from 0 ($P_L < 0.01$; $P_Q < 0.01$). A similar relationship was observed for FCM: FCM yield (kilograms per day) = –1.86 + 18.52 × RDS (kilograms per day) – 3.45 × $RDS^2$ (kilograms per day); the linear and quadratic regression coefficients were significantly different from 0 ($P_L = 0.01$, $P_Q = 0.02$). Relationships between intake of RDS and milk component yields and percentages were not significant.

In our study, NDF from forage was maintained at a constant concentration, and maximum milk and FCM yields occurred at an estimated RDS intake of 2.7 kg/d; a decline in yield was detected at a higher intake of RDS. This result contrasts with the conclusion of Nocek and Tamminga (20), based on a literature survey of 60 diets supplying more forage fiber than the diets used in our study and ranging in RDS intake from 1.8 to 6.4 kg/d, that maximum milk yield is attained by maximizing the intake of RDS. Our results seemed to indicate that higher concentrations of effective fiber are necessary when the intake of RDS is high; if not, a high intake of RDS actually lowers milk yield, as indicated by the curvilinear response observed in our study.

Because the diets in this study were formulated on the basis of NSC concentrations without considering the availability of NSC or RDS, the differences in milk yield and composition that were observed among diets were mainly attributed to the source of cereal grain, specifically source of NSC, rather than to the percentage of NSC. When diets are formulated on the basis of NSC content and using a broad range of feed grains and ingredients, differences in ruminal availability must be considered.

## CONCLUSIONS

For high concentrate diets that contained low concentrations of NDF from forage, a reduction in the NSC content of concentrates based on corn or barley using oat hulls tended to improve the DMI of older cows. However, dietary NSC had no effect on milk or FCM yields of primiparous or multiparous cows, and a reduced percentage of NSC did not improve feed efficiency. When corn and barley diets were considered individually or in combination, no consistent relationship was observed between the amount of NSC consumed and milk yield or composition. However, when ruminal availability of NSC was taken into account, a significant curvilinear relationship was observed between intake of RDS and milk or FCM yield. When diets are formulated on the basis of NSC using a variety of ingredients, accounting for differences in ruminal availability of carbohydrates may help provide an optimal supply of energy precursors to the mammary gland.

For diets that were formulated to contain similar NSC and $NE_L$ concentrations, milk yield and feed efficiency were similar when concentrates were based on corn or barley, but yields and feed efficiency were lower when hull-less barley was used, likely because of ineffective processing. Longer term lactation studies with high yielding cows are necessary to confirm the results obtained with hull-less barley in this study. Further research must ascertain whether the optimal degree of grain processing differs for hull-less barley and hulled barley.

## ACKNOWLEDGMENTS

The authors thank B. I. Farr, G. Stordahl, S. Eivemark, and K. Lynch-Staunton for their technical assistance during experimentation and for performing laboratory analyses. The authors also recognize the valuable contribution of G. Steacy, R. Reid, and the staff of the Lethbridge Research Centre Dairy Unit. This research was financially supported by Alberta Agriculture Research Institute and the Canada/Alberta Livestock Research Trust.

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