Effect of Grains Differing in Expected Ruminal Fermentability on the Productivity of Lactating Dairy Cows

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ABSTRACT

The objective of the study was to evaluate the effect of barley and corn grains differing in expected fermentability in the rumen on dry matter intake (DMI) and productivity of lactating dairy cows. Twenty-two multiparous and 9 primiparous lactating Holstein cows (94 ± 29 d in milk; mean $\pm$ SD) were used in a 3×3 Latin square design with 21-d periods. Experimental diets contained approximately 40% of dietary dry matter as steam-rolled barley, using a lot of cultivar Dillon or cultivar Xena, or a corn mixture (CM) containing 87.5% dry ground corn, 11.4% beet pulp, and 1.1% urea (dry matter basis). Starch concentration of the grain sources was 50.0, 58.7, and 60.4% and in vitro 6-h starch digestibility was 73.5, 78.0, and 71.0%, respectively, for Dillon, Xena, and CM. All diets were formulated to contain 19.4% crude protein and 25.3% forage neutral detergent fiber. Dry matter intake (23.6 vs. 21.6 kg/d) and yields of milk (40.4 vs. 37.4 kg/d), milk protein (1.20 vs. 1.12 kg/d), and milk lactose (1.85 vs. 1.74 kg/d) were higher for cows fed CM than for cows fed barley. Although DMI was similar for cows fed Xena and Dillon (21.9 vs. 21.4 kg/d), cows fed Xena had higher yields of milk (38.5 vs. 36.2 kg/d), milk protein (1.18 vs. 1.07 kg/d), and milk lactose (1.80 vs. 1.69 kg/d) than cows fed Dillon. However, milk fat concentration tended to be higher (3.47 vs. 3.23%) for cows fed Dillon than Xena. Plasma glucose and nonesterified fatty acid concentrations were not affected by treatment, but plasma insulin concentration was higher for cows fed Xena compared with those fed Dillon (8.50 vs. 5.91 μ IU/mL). Greater milk production for cows fed CM can be attributed to greater DMI. Feeding barley that was lower in starch concentration and ruminal starch fermentability (Dillon) did not increase DMI compared with feeding barley that was higher in starch concentration and ruminal starch fermentability (Xena). Reducing ruminal starch

degradation of barley grain may not improve the productivity of lactating dairy cows.

Key words: barley, starch digestibility, milk production, dairy cow

INTRODUCTION

Barley is the primary grain fed to ruminants in the northwestern United States, western Canada, and Europe. Barley is highly degradable in the rumen and often causes production of excess fermentation acid, decreasing rumen pH (McCarthy et al., 1989; Robinson and Kennelly, 1989; Nocek and Tamminga, 1991). Overton et al. (1995) fed dairy cows diets containing 5 different ratios of starch from ground shelled corn and steam-rolled barley and found that DMI and milk yield decreased as the ratio of starch from steam-rolled barley increased. A rapid rate of carbohydrate degradation is associated with sharp reductions in DMI and milk production (McCarthy et al., 1989; Aldrich et al., 1993; Mitzner et al., 1994). Thus, the decreased DMI and productivity for cows fed barley grain compared with corn grain might be caused in part by rapid fermentation in the rumen.

A significant variation exists in the chemical composition of barley grain. Barley grain has been reported to vary from 7.5 to 15% in CP concentration (LaFrance and Watts, 1986), from 17 to 32% in NDF concentration (Ovenell-Roy et al., 1998b), and from 45.9 to 62.8% in starch concentration (Ovenell-Roy et al., 1998b). Furthermore, Khorasani et al. (2000) reported that the rate of in situ DM degradation varied from 20.0 to 64.4%/h among 60 lots of barley grain cultivars. Yu et al. (2004) showed distinctive differences in chemical and structural endosperm matrix makeup between the barley cultivars Valier and Harrington using infrared microspectroscopy, and these differences are expected to affect the rate of starch degradation in the rumen.

Barley grain differing in chemical or physical characteristics is expected to affect the productivity of animals. For example, barley cultivars varying in nutrient composition affect the feed efficiency of beef cattle (Boss

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Table 1. Nutrient composition of the grains used to formulate the experimental diets¹

Item	CM	Dillon	Xena
Test weight, kg/hL	—	61.5	75.3
DM, %	95.1	89.6	87.7
CP, % of DM	12.8	10.1	12.6
Soluble protein, % CP	2.2	2.0	2.3
ADF, % of DM	3.7	8.1	3.7
NDF, % of DM	14.3	27.0	19.0
Ether extract, % of DM	2.8	2.2	2.0
Ash, % of DM	1.6	2.9	2.8
Starch, % of DM	60.4	50.0	58.7
In vitro 6-h starch digestibility, % starch	71.1	73.5	78.0

¹CM = corn mix containing 87.5% dry ground corn, 11.4% beet pulp, and 1.1% urea (DM basis); Dillon = steam-rolled barley, cultivar Dillon; Xena = steam-rolled barley, cultivar Xena.

and Bowman, 1996; Zinn et al., 1996). However, little research has been conducted to evaluate the effects of barley grain cultivars on the productivity of lactating dairy cows. We hypothesized that barley grain varying in physical and chemical characteristics would affect the productivity of lactating dairy cows. Further, because excess fermentation in the rumen often decreases DMI (Allen, 2000), we also hypothesized that DMI and milk production of cows fed a less fermentable source of barley would be similar to cows fed corn. Therefore, the objective of this study was to evaluate the effect of grains differing in starch content and expected fermentability in the rumen on DMI and productivity of lactating dairy cows.

MATERIALS AND METHODS

Cows, Diets, and Treatments

Twenty-two multiparous and 9 primiparous Holsteins cows in early to midlactation (94 ± 29 DIM; $\bar{X} \pm$ SD) from the University of Alberta Dairy Research and Technology Centre were randomly assigned to a treatment sequence within a 3×3 Latin square balanced for carryover effects. At the beginning of the experiment, cows averaged 626 ± 84 kg and BCS was 3.0 ± 0.35 . Treatment periods were 21 d, with the final 7 d used to collect samples and data. Cows were cared for according to guidelines of the Canadian Council on Animal Care (Institutional Animal Use Approval Number: 2005-13C).

Two 15-t lots of barley grain, cultivars Xena and Dillon, were obtained from a local grain company. These 2 lots were selected because of the distinctive differences in their physical and chemical characteristics (Table 1). A corn mixture (CM) containing 87.5% dry ground corn, 11.4% beet pulp, and 1.1% urea on a DM basis was prepared. The CM was designed to approximate the CP and starch concentrations of barley grains.

Table 2. Ingredients and nutrient composition of experimental diets containing either a corn mixture (CM)¹ or steam-rolled barley, cultivar Dillon or cultivar Xena (% of DM)

Item	CM	Barley	
		Dillon	Xena
Ingredient			
Barley silage	26.6	27.3	27.4
Alfalfa hay	15.8	16.1	16.2
Basal concentrate mix ²	17.0	17.5	17.5
CM	40.6	—	—
Dillon, steam-rolled	—	39.1	—
Xena, steam-rolled	—	—	38.9
Nutrient composition			
Forage NDF	25.1	25.3	25.5
NDF	33.0	39.3	37.5
CP	19.4	19.4	19.6
Starch	28.7	22.3	25.3
Ether extract	3.0	2.6	2.3

¹CM = corn mixture containing 87.5% dry ground corn, 11.4% beet pulp, and 1.1% urea (DM basis).

²Basal concentrate mix contained 10% beet pulp, 10% Megalac (Church and Dwight, Princeton, NJ), 0.5% vegetable oil, 17.5% fish meal, 14% corn meal, 22% canola meal, 3.8% limestone, 1.2% magnesium oxide, 1.9% sodium bicarbonate, 7.7% calcium phosphate, and 11.4% premix of microminerals and vitamins (DM basis).

Starch concentration was 50.0, 58.7, and 60.4% and 6-h in vitro starch digestibility was 73.5, 78.0, and 71.0%, respectively, for Dillon, Xena, and CM. Although actual ruminal starch digestion of grains was not measured in this study, it was expected to differ because of the differences in starch concentration and 6-h in vitro starch digestibility. Furthermore, a subsequent companion study with ruminally and intestinally cannulated cows confirmed these differences in fermentability (Silveira et al., 2007). Three experimental diets were formulated to contain approximately equal amounts of steam-rolled barley, using either Dillon or Xena, or CM (Table 2). All diets were designed to meet or exceed requirements for CP, RUP, vitamins, and minerals (NRC, 2001). The diets were formulated to contain 19.4% CP and 25.3% forage NDF concentrations. Throughout the experiment, cows were housed in tie stalls with continuous access to water. The experimental TMR was offered once daily (0900 h) at 110% of expected intake and cows were milked in their stalls twice daily (0600 and 1700 h). Animals were allowed to exercise once daily (1100 h) for 2 h.

Data and Sample Collection

Body weight was recorded on 2 consecutive days immediately prior to the start of the first period and on the last 2 d of each period. Body condition score was determined by 2 trained individuals at the beginning of the experiment and at the end of each period (a 5-point scale was used, with 1 = thin and 5 = fat; Wildman

et al., 1982). The amount of feed offered and orts were weighed and recorded daily during the collection period. Representative samples of all dietary ingredients, TMR, and orts (approximately 12.5%, as-fed basis) were collected daily during the collection period. The orts were pooled and one sample was retained per cow per period. The DM content of barley silage and alfalfa hay was determined weekly to adjust dietary allocation of forages to maintain a consistent forage-to-concentrate ratio. Milk yield was measured daily and averaged over the 7-d collection period. Milk was sampled at every milking on d 19, 20, and 21 of each period and milk component concentrations (weighed by yield at each milking daily) and yields were averaged for these dates. Fecal and blood samples were collected from each cow on d 15 to 21 every 28 h to account for diurnal variations (1100 h on d 15, 1500 h on d 16, 1900 h on d 17, 2300 h on d 18, 0300 h on d 20, and 0700 h on d 21). Fecal samples (150 g) were collected from the rectum, frozen at -20°C , and composited into one sample per cow per period immediately prior to drying in a forced-air oven. Blood was sampled from the coccygeal vessels using Vacutainer tubes containing sodium heparin (Becton Dickinson, Franklin Lakes, NJ). Blood samples were immediately placed on ice and centrifuged within 1 h at 4°C for 30 min at $3,000 \times g$. Plasma was harvested and stored at -20°C until further analysis.

Sample Analysis

Diet ingredients, orts, and feces were dried in a 55°C forced-air oven for 72 h to determine DM concentration. The dried samples were ground through a 1-mm screen using a Wiley mill (Thomas-Wiley, Philadelphia, PA). Samples were analyzed for concentrations of DM, ash, NDF, indigestible NDF, CP, ether extract (EE), and starch. Dry matter concentration was determined after drying samples at 135°C for 2 h (AOAC, 2002; method 930.15). Ash concentration was determined after 5 h at 550°C in a furnace (AOAC 2002; method 942.05). Neutral detergent fiber concentration was determined using amylase and sodium sulfite (Van Soest et al., 1991). Crude protein concentration was quantified by flash combustion with gas chromatography and thermal conductivity detection (Carlo Erba Instruments, Milan, Italy; Rhee et al., 2005). Starch was measured by an enzymatic method (Karkalas, 1985) after samples were gelatinized with sodium hydroxide, with glucose concentration measured using a glucose oxidase/oxidase enzyme (No. P7119, Sigma, St. Louis, MO) and dianisidine dihydrochloride (No. F5803, Sigma). Absorbance was determined with a plate reader (SpectraMax 190, Molecular Devices Corp., Sunnyvale, CA). Ether extract concentration was determined using a

Goldfish extraction apparatus (Labconco, Kansas City, MO; Wrolstad et al., 2005). Indigestible NDF was determined as NDF residue after 120-h incubation in the rumen, and was used as an internal marker to determine apparent total tract nutrient digestibility (Cochran et al., 1986).

The TMR and orts samples were analyzed for particle size distribution using a Penn State Forage Particle Separator (19.0-, 8.0-, and 1.18-mm sieves; Nasco, Fort Atkinson, WI) to determine the extent of sorting, which was expressed as a sorting index. The sorting index was calculated as the actual intake/expected intake for each portion retained on the individual screens. Expected intake was calculated as the particle size distribution of the TMR (% as-fed basis) $\times$ actual as-fed intake. Actual intake was calculated as the amount of feed offered $\times$ particle size distribution in the TMR (% as-fed basis) – the amount feed refused $\times$ the particle size distribution in the orts samples (%). A sorting index of 1, less than 1, and greater than 1 indicated no sorting, sorting against, and sorting for, respectively (Leonardi and Armentano, 2003).

Milk fat, protein, lactose, and SCC concentrations were measured with infrared spectroscopy by Edmon-ton-Alberta DHIA (MilkOScan 605, Foss Electric, Hillerød, Denmark), MUN was determined with an automated infrared Fossomatic 400 milk analyzer (Foss North America, Brampton, Ontario, Canada). Milk energy output was calculated according to the NRC (2001) using measured concentrations of milk fat, protein, and lactose. Commercial kits were used to determine plasma concentrations of insulin (Coat-A-Count, Diagnostic Products Corporation, Los Angeles, CA) and NEFA (NEFA C-kit, Wako Chemicals USA, Richmond, VA) using a previously described protocol modification (Johnson and Peters, 1993). Plasma glucose concentration was measured using a glucose oxidase/oxidase enzyme and dianisidine dihydrochloride as described above.

Statistical Analysis

All data were analyzed using the fit model procedure of JMP (version 5.1, SAS Inc., Cary, NC) according to the following model:

$$Y_{ijkl} = \mu + C_i + P_j + T_k + e_{ijkl}$$

where μ is the overall mean, C_i is the random effect of cow ($i = 1$ to 31), P_j is the fixed effect of period ($j = 1$ to 3), T_k is the fixed effect of treatment ($k = 1$ to 3), and e_{ijkl} is the residual, assumed to be normally distributed.

The parity $\times$ treatment interaction was originally included in the model, but it was later removed because

Table 3. The DMI and performance of lactating dairy cows fed diets containing either a corn mixture (CM)¹ or steam-rolled barley, cultivar Dillon or cultivar Xena

Item	CM	Barley		SE	P-value	
		Dillon	Xena		CM vs. barley	Dillon vs. Xena
DMI, kg/d	23.6	21.4	21.8	0.7	<0.001	0.35
Sorting index ²						
First (top) sieve, 19-mm	1.03	0.96	0.93	0.03	0.02	0.46
Second sieve, 8-mm	0.96	1.02	1.03	0.02	<0.01	0.51
Third sieve, 1.18-mm	1.02	1.02	1.01	0.01	0.65	0.45
Collection pan	1.15	1.05	1.03	0.06	0.13	0.75
Yield, kg/d						
Milk	40.4	36.2	38.5	1.2	<0.01	0.04
Milk fat	1.33	1.26	1.23	0.06	0.10	0.55
Milk protein	1.20	1.07	1.18	0.04	<0.001	<0.001
Milk lactose	1.85	1.69	1.8	0.07	<0.01	<0.01
Milk composition, %						
Milk fat	3.39	3.47	3.23	0.13	0.72	0.08
Milk protein	2.99	2.89	3.08	0.06	0.85	<0.001
Milk lactose	4.65	4.49	4.62	0.06	0.06	0.03
SCC, 10 ³ /mL	147	331	229	114	0.21	0.78
MUN, mg/dL	14.7	14.7	14.3	0.4	0.66	0.28
4% FCM yield, kg/d	36.1	33.3	33.9	1.1	<0.01	0.54
NE _L milk output, ³ Mcal/d	26.5	23.6	24.8	0.8	<0.001	0.12
Milk yield/DMI	1.74	1.71	1.77	0.05	0.90	0.24
NE _L milk output/NE _L intake ⁴	0.80	0.86	0.88	0.26	0.02	0.53
BW change, kg/d	-0.23	0.12	-0.53	0.12	0.87	<0.001
BCS change, per 21 d	0.02	0.01	0.06	0.03	0.63	0.24

¹CM = corn mixture containing 87.5% dry ground corn, 11.4% beet pulp, and 1.1% urea (DM basis).

²Sorting index = actual intake/expected intake (<1 sorting against, >1 sorting for, and =1 no sorting)

³Milk energy output was calculated from measured milk yield and concentrations of milk fat, protein, and lactose according to the NRC (2001): NE_L (Mcal/kg) = 0.0929 × fat % + 0.0547 × CP % + 0.0395 × lactose %.

⁴NE_L intake was calculated from DMI and measured NE_L content of diets; digestible energy content of diets was first calculated from nutrient components actually digested in the total tract, and then converted to NE_L according to the NRC (2001): ME_P (Mcal/kg) = 1.01 × digestible energy (Mcal/kg) – 0.45; NE_L (Mcal/kg) = [0.703 × ME_P (Mcal/kg)] – 0.19.

the interaction was not significant for all response variables. Orthogonal contrasts were made to evaluate the effect of CM vs. barley (mean of Dillon and Xena) and the effect of Dillon vs. Xena.

RESULTS

The diets contained about 39% barley grains or 40.6% CM. Because the DM concentration of CM ingredient samples collected during the study was greater than expected, the diet actually contained slightly more CM than the 39% intended (DM basis; Table 2). The grain sources were added to the diet in approximately equal proportions; thus, the starch content of the diet was highest for CM, intermediate for Xena, and lowest for Dillon.

Cows fed CM had greater DMI compared with cows fed barley grain (23.6 vs. 21.6 kg/d; $P < 0.001$; Table 3). Dry matter intake was not affected by the barley cultivar (21.8 vs. 21.4 kg/d; $P = 0.35$). Cows fed CM sorted for longer particles (i.e., feed on the top sieve; $P = 0.02$) and against medium-length particles on the second

sieve ($P < 0.01$) of the particle size separator to a greater extent than cows fed barley. There were no differences in sorting between the barley treatments. Apparent total tract digestibility of DM (64.9 vs. 60.5; $P < 0.001$; Table 4), OM (69.7 vs. 65.7%; $P < 0.001$), starch (97.7 vs. 94.1%; $P < 0.001$), and EE (83.3 vs. 77.6%; $P < 0.001$) were higher for the CM treatment compared with barley grain treatments. Apparent total tract digestibility of starch was greater (95.6 vs. 92.6%; $P < 0.001$) and that of EE was lower (75.7 vs. 79.5%; $P < 0.001$) for Xena compared with Dillon. Apparent total tract digestibility of CP and NDF was not affected by treatment.

Daily yields of milk (40.4 vs. 37.4 kg/d; $P < 0.01$), milk protein (1.20 vs. 1.12 kg/d; $P < 0.001$), and milk lactose (1.85 vs. 1.74 kg/d; $P < 0.01$) were higher for cows fed CM than for cows fed barley grain. Milk fat yield (1.33 vs. 1.24 kg/d; $P = 0.10$) and milk lactose concentration (4.65 vs. 4.55%; $P = 0.06$) tended to be higher for cows fed CM diets compared with cows fed barley grain. Daily yields of milk (38.5 vs. 36.2 kg/d; $P = 0.04$), milk protein (1.18 vs. 1.07 kg/d; $P < 0.001$), and lactose (1.80 vs. 1.69 kg/d; $P < 0.01$) were higher for cows fed Xena compared

Table 4. Apparent total tract nutrient digestibility of lactating dairy cows fed diets containing either a corn mixture (CM)¹ or steam-rolled barley, cultivar Dillon or cultivar Xena

Digestibility, %	CM	Barley		SE	P-value	
		Dillon	Xena		CM vs. barley	Dillon vs. Xena
DM	64.9	60.1	60.8	0.8	<0.001	0.52
OM	69.7	65.5	66.0	0.7	<0.001	0.61
Starch	97.7	92.6	95.6	0.4	<0.001	<0.001
Ether extract	83.3	79.5	75.7	0.7	<0.001	<0.001
CP	68.2	67.8	66.7	0.7	0.32	0.34
NDF	46.2	46.9	46.5	1.3	0.73	0.80

¹CM = corn mixture containing 87.5% dry ground corn, 11.4% beet pulp, and 1.1% urea (DM basis).

with those fed Dillon. Concentrations of milk protein (3.08 vs. 2.89%; $P < 0.001$) and milk lactose (4.62 vs. 4.49%; $P = 0.03$) were also higher for Xena compared with Dillon. However, milk fat concentration tended to be higher (3.47 vs. 3.23%; $P = 0.08$) for cows fed Dillon than those fed Xena. The SCC and MUN were not affected by treatment.

Cows fed Dillon gained more BW (0.16 vs. -0.53 kg/d) than cows fed Xena, although a treatment effect was not observed for the comparison between CM and barley grain treatments. The BCS was also not affected by treatment. Cows fed CM had a higher 4% FCM yield (36.1 vs. 33.6 kg/d; $P < 0.01$) and milk energy output (26.5 vs. 24.2 Mcal/d; $P < 0.001$) compared with cows fed barley. Energy utilization efficiency, defined as net energy output of milk divided by net energy intake, was higher for barley compared with the CM treatment (86.9 vs. 80.1%; $P = 0.02$). Plasma concentrations of glucose and NEFA were not affected by treatment (Table 5). Plasma insulin concentration was higher for cows fed Xena than Dillon (8.50 vs. 5.91 μ IU/mL; $P < 0.01$), but no difference was observed between CM and barley grain treatments.

DISCUSSION

Corn vs. Barley

Replacing corn with barley reduced DMI of lactating dairy cows by about 2 kg/d. This reduction in DMI is

similar to that reported in some studies (Casper and Schingoethe, 1989; McCarthy et al., 1989; Casper et al., 1990; Khorasani et al., 1994; Yang et al., 1997b), although other studies have not observed low intake among cows fed barley diets (De Peters and Taylor, 1985; Grings et al., 1992; Casper et al., 1999). Inconsistent effects of grain source on DMI can be attributed to the proportion of grain in the diet (DeVisser et al., 1990; Grings et al., 1992), the starch concentration of the diet (Tommervik and Waldern, 1969; Rode and Satter, 1988; DeVisser et al., 1990), and forage particle length (Rode and Satter, 1988). Diets containing higher concentrations of forage NDF promote chewing, salivation, and high rumen pH (Mertens, 1997), which mask some effects caused by differences in fermentability of diets in the rumen.

Milk yield was greater for cows fed CM although efficiency for milk production, defined either as milk yield/DMI or as NE_L milk/NE_L intake, was not greater for the CM treatment. Thus, the higher milk yield of cows fed CM was attributed to greater DMI. Some previous research also reported a higher DMI and milk yield for corn-based diets compared with barley-based diets (McCarthy et al., 1989; Overton et al., 1995; Casper et al., 1999). However, other research observed no treatment effect on milk yield (Grings et al., 1992; Khorasani et al., 1994). The lack of effect of grain source on milk lactose, fat, and protein concentrations is consistent with some previous studies, but the effects of replacing

Table 5. Plasma metabolite concentrations of lactating dairy cows fed diets containing either a corn mixture (CM)¹ steam-rolled barley, cultivar Dillon or cultivar Xena

Plasma metabolite	CM	Barley		SE	P-value	
		Dillon	Xena		CM vs. barley	Dillon vs. Xena
NEFA, mEq/L	102.0	120.7	104.4	8.0	0.32	0.24
Glucose, mg/dL	61.3	60.3	61.1	0.7	0.32	0.24
Insulin, μ IU/mL	7.44	5.91	8.50	0.64	0.64	<0.01

¹CM = corn mixture containing 87.5% dry ground corn, 11.4% beet pulp, and 1.1% urea (DM basis).

corn with barley resulted in inconsistent effects on milk components. For example, Casper et al. (1990) reported that milk fat increased when corn replaced barley, but other research (De Peters and Taylor, 1985; Bilodeau et al., 1989; Casper and Schingoethe, 1989; McCarthy et al., 1989) found no differences in milk fat content. Milk lactose and protein concentrations were not different between barley- and corn-based diets in previous studies (De Peters and Taylor, 1985; Bilodeau et al., 1989; McCarthy et al., 1989; Grings et al., 1992).

Effects of Barley Grain Treatments

We used 2 barley cultivar lots, Dillon and Xena, to test our hypothesis that less ruminally fermentable barley grain would increase the productivity of dairy cows compared with more fermentable barley grain. The Xena barley used in this study had a greater starch concentration (58.7 vs. 50.0% of DM) and greater *in vitro* 6-h starch digestibility (78.0 vs. 73.5%) compared with Dillon barley. Although actual ruminal starch digestion was not determined in this study, the higher plasma insulin concentration (8.50 vs. 5.91 μ IU/mL) and apparent total tract starch digestibility (95.6 vs. 92.6%) for cows fed Xena compared with Dillon were consistent with the expected greater ruminal starch digestion for Xena compared with Dillon. Furthermore, a companion study conducted with the same lots of Xena and Dillon found that ruminally cannulated dairy cows fed Xena had greater propionate concentration in ruminal fluid and a longer time that rumen pH was below 5.8 compared with cows fed Dillon (Silveira et al., 2007).

We expected less reduction in feed intake for cows fed Dillon compared with Xena because of the slower ruminal fermentation of Dillon. Contrary to expectations, DMI was not different between Xena and Dillon. Our findings are in agreement with Yang et al. (1997a), who compared hull-less barley with hulled barley and corn grain. They reported that DMI was reduced by 1.3 kg/d for cows fed barley compared with corn grain, but they did not observe a difference in DMI between barley grain treatments although hull-less barley was more slowly digested in the rumen than hulled barley (Yang et al., 1997a). Excess fermentation in the rumen is generally considered as the primary cause of lower DMI and milk yield for cows fed barley grains compared with corn grain (McCarthy et al., 1989; Overton et al., 1995). Ruminal concentration of propionate is typically higher for barley-based diets than corn-based diets (McCarthy et al., 1989; Overton et al., 1995), which is consistent with the hypophagic effect of propionate in ruminant animals (Allen, 2000) and decreases energy intake (Oba and Allen, 2003). However, barley grains that are less

fermentable in the rumen did not prevent a reduction in DMI in the study of Yang et al. (1997b) nor in our study, which indicates that the lower DMI often observed for cows fed barley grains compared with corn grains cannot be solely attributed to excess fermentation or hypophagic effects of propionate.

Because DMI was not different between Xena and Dillon, the greater milk yield of cows fed Xena compared with Dillon is attributed to the higher starch content of the Xena diet coupled with its higher total tract starch digestibility. Cows fed Xena tended to have a lower milk fat concentration, which is consistent with the expected greater starch digestion in the rumen for the Xena treatment. As rumen pH declines, the biohydrogenation of unsaturated fatty acids is disrupted, increasing the accumulation of *trans*-18:1, which depresses *de novo* fatty acid synthesis in the mammary gland (Griinari et al., 1998). Greater milk protein concentration for the Xena treatment can be attributed to the expected greater ruminal starch digestion. The higher propionate concentration in ruminal fluid from cows fed Xena (Silveira et al., 2007) would have favored the use of propionate by the liver for gluconeogenesis to a greater extent than for cows fed Dillon. Increased gluconeogenesis has a sparing effect on AA, increasing the availability of AA for milk protein synthesis in the mammary gland. Greater milk protein concentration for cows fed Xena compared with those fed Dillon can be also attributed to the greater plasma insulin concentration (Mackle et al., 1999).

The effects of barley grain cultivar on animal productivity have been studied for beef cattle. Bradshaw et al. (1996) fed 2 barley cultivars with the same test weight (67 kg/hL), Steptoe and Klages, to growing steers (31% barley in the diet) and finishing steers (87% barley in the diet) and found no differences in steer performance. However, when 6 studies were performed over 5 yr, Klages increased weight gain in one study, decreased weight gain in 2 studies, and resulted in no difference in gain in the remaining 3 studies (Kercher et al., 1986). Ovenell-Roy et al. (1998a,b) fed 6 barley cultivars to steers in finishing diets and found that digestibility of NDF was the main factor contributing to cultivar differences, where the cultivar with the lowest NDF digestibility tended to have lower starch and digestible energy contents. Covered (Leduc, 61.9 kg/hL) and hull-less (Condor, 76.1 kg/hL) barley was fed to steers in finishing diets (77% barley in the diet) and gain was found to be similar for both cultivars; however, cattle fed Leduc had higher intake, leading to decreased feed efficiency and dietary energy density (Zinn et al., 1996). A study evaluating 3 cultivars, Gunhilde (2-row, 64.5 kg/hL), Harrington (2-row malting, 63.1 kg/hL), and Medallion (6-row, 61.9 kg/hL), concluded that Me-

dallion had the better feed conversion when fed to steers in finishing diets (80% barley in the diet), followed by Gunhilde and Harrington (Boss and Bowman, 1996).

The effects of barley grain differing in nutrient composition were studied to some extent using lactating dairy cows (Yang et al., 1997a,b; Foley et al., 2006), but most research evaluating barley grain using dairy cows has compared the feeding value of barley grain with that of corn grain, overlooking the variation within barley grain. We found significant differences in milk protein concentration and plasma insulin concentration between barley grain treatments, but not between CM and barley treatments. These observations indicate that selection of barley grain can affect some nutrient metabolism and milk production responses to a greater extent than selection of grain type (i.e., corn vs. barley). Selection of barley cultivar can be a viable management option to enhance the productivity of dairy cows, but our research data need to be interpreted with caution. Although we found greater milk yield for cows fed Xena compared with those fed Dillon, it cannot be concluded that Xena is a better cultivar than Dillon for lactating dairy cows. Effects of the growing environment and interactions of barley genetics with its growing environment are expected to greatly affect the physical and chemical characteristics of barley grains. In the current study, Xena was compared with Dillon, but it is not known whether the lots of grain used in this study are representative of each cultivar. However, our study clearly demonstrates that selection of barley grain can affect the productivity of lactating dairy cows. Further research is warranted to identify the quality traits of barley grain that influence the productivity of lactating dairy cows.

CONCLUSIONS

Cows fed corn had higher DMI and milk production compared with those fed barley grain. However, despite expected lower ruminal starch digestion caused by lower starch content and reduced fermentability, cows fed Dillon had similar DMI as cows fed Xena. Milk yield and milk protein concentration were lower for cows fed Dillon compared with cows fed Xena, indicating that reducing the ruminal starch digestion of barley grain may not improve the productivity of lactating dairy cows. Barley grain fed to ruminants needs to be carefully selected because of large variations in nutrient composition and digestibility across the lots and their effects on productivity of lactating dairy cows. Future research needs to identify the quality traits of barley grain that affect the productivity of animals.

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