Performance, carcass quality and blood metabolites of Holstein bulls on feedlot feeding of different proportions of barley grain to maize grain

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ABSTRACT. This experiment was conducted to study the effects of five different ratios of barley grain to maize grain: 1) 100:00, 2) 75:25, 3) 50:50, 4) 25:75, and 5) 00:100 on feedlot performance, carcass quality, ruminal and blood parameters of twenty-five Holstein bulls. Quadratic effects were detected for carcass efficiency and were greatest for diets with barley grain-to-maize grain ratios of 75:25 and 50:50 compared with other diets. Also, back-fat thickness, abdominal fat, and meat ether extract increased as the proportion of maize increased in the diets (P < 0.05). When the proportion of maize in diets increased, the amount of undigested grain in feces increased linearly (P < 0.05). At 3 and 6 h after feeding, as the proportion of barley increased in the diets, ruminal pH decreased quadratically. We conclude that feeding bulls diets based on 50:50 and 75:25 barley-to-maize grain ratios resulted in higher carcass efficiency and optimal ruminal parameters.

Introduction

In ruminants fed high-grain diets, feeding barley starch has been linked to an increased incidence of digestive disorders (Givens et al., 1993; Ørskov, 1986). Rapid fermentation of barley starch increases the acidity of the rumen, which negatively affects the action of fiber-digesting bacteria and shortens retention time in the rumen. Rapid fermentation of barley in the rumen also increases the incidence of bloating, acidosis, laminitis, liver abscesses, and feed intake problems related to digestive upsets (Haddad and Nasr, 2007). On the other hand, barley starch is more rapidly and thoroughly fermented in the rumen than maize starch, which can result in greater microbial protein synthesis (Feng et al., 1995). Between 80% and 90% of barley starch and wheat starch is digested in the rumen, whereas the values for sorghum and maize range from 55% to 70% (Nocek and Tamminga, 1991). Thus, relative to barley, a greater proportion of maize starch may reach the small intestine. Digestion of starch in the small intestine has been reported to be more efficient than its digestion and absorption of the resulting volatile fatty acids (VFA) in the rumen (Boss and Bowman, 1996; Owens et al., 1986). Therefore, feeding a mixture of rapidly (e.g., barley) and slowly (e.g., maize) digested cereal grains may reduce the incidence of acidosis and result in a favorable balance of starch digestion in the rumen and postruminal tract, improving feed efficiency as compared with diets based primarily on one type of grain (Mendoza et al., 1990).

Most of the previous experiments have used factorial designs in which the quantity of one source of nonstructural carbohydrate was totally replaced with a similar quantity of another source of nonstructural carbohydrate. Few studies have been conducted to determine the effect of different proportions of two sources of nonstructural carbohydrates in the same diet. Therefore, the objective of this study was to investigate ruminal fermentation, plasma metabolites, and performance of bulls fed different proportions of barely and maize in their diets.

Material and methods

Animals and diets

The protocol for this study was approved by the University of Tehran Institutional Animal Care and Use Committee. Twenty-five Holstein bulls (average initial age 8.5 months, initial body weight 276 ± 29 kg with restriction of feed for 16 h) were fed finishing diets for 110 days (20-day adaptation period plus 90-day experimental period). The diets were total mixed rations with five different ratios of barley to maize grain, viz.: 1) 100:00, 2) 75:25, 3) 50:50, 4) 25:75 and 5) 0:100. The diets contained 25% forage (12.5% lucerne and 12.5% maize silage in total dry matter (DM)) and 75% concentrate balanced according to NRC 1996 recommendation (Table 1). Grains were milled to pass through a 3 mm screen. The bulls were housed in individual tie stalls and had free access to water. They were fed twice daily at 08:00 and 15:00 h.

Sampling and chemical analysis

Dry matter intake was measured daily and feed orts were collected daily. Dry matter, ash, neutral detergent fibre (NDF) without ash, and crude protein (CP) of samples were determined according to AOAC (2000) at the nutrition laboratory of Tehran University (Table 1). The nonstructural carbohydrate content (percentage of DM) of diets was calculated as: $100 - (NDF\% + CP\% + \text{ether extract}\% + \text{ash}\%)$. Diet apparent digestibility was estimated using acid insoluble ash (AIA) as an internal marker. Diet and feces samples for the bulls were analyzed for AIA (Van Keulen and Young, 1977), and the feed-to-gain ratio (F : G) was calculated.

For measurements of ruminal parameters, ruminal fluid was collected by rumenocentesis at 0 (just before the morning feeding), 3, and 6 h after feeding, according to the technique described by Nordlund and Garrett (1994). Briefly, the procedure

Table 1. Composition of finishing diets based on different proportion of barley to maize grain

Item	Diets[1]				
	1	2	3	4	5
Ingredient, % of DM					
maize silage	12.50	12.50	12.50	12.50	12.50
lucerne hay, chopped	12.50	12.50	12.50	12.50	12.50
maize grain	0	13.29	27.57	41.85	55.14
barley grain	55.14	41.85	27.57	13.29	0
soyabean meal	10.4	11	11.5	12	12.2
canola meal	2.56	2.56	2.56	2.56	2.56
wheat bran	1.4	1.4	1.4	1.4	1.4
beet pulp, dehydrated	2.2	1.6	1.1	0.6	0.4
NaCl	0.3	0.3	0.3	0.3	0.3
limestone	1	1	1	1	1
zeolite	1.2	1.2	1.2	1.2	1.2
vitamin-mineral permix[2]	0.8	0.8	0.8	0.8	0.8
Chemical composition					
dry matter, %[4]	71.02	71.32	71.23	71.90	71.97
crude protein, % of DM[4]	15.60	15.60	15.40	15.40	15.40
neutral detergent fibre, % of DM[4]	37.2	36.90	36.30	33.06	32.01
metabolizable energy, Mcal·kg^{-1} [3]	2.55	2.58	2.63	2.65	2.66
DIP, % of crude protein[3]	66.40	66.90	65.20	65.30	64.10
UDP, % of crude protein[3]	33.60	34.10	34.80	34.70	35.90

[1] diets consisted: 1. 100:00; 2. 75:25; 3. 50:50; 4. 25:75; 5. 00:100 ratio of barley to maize grain, respectively; [2] one kg of vitamin-mineral permix Contained: IU . kg^{-1}: vit. A 600.000, vit. D 200.000: mg . kg^{-1}: 200 vit. E: mg: antioxidant 2500: g: Ca 195, P 80, Mg 21, Mn 2.2, Cu 0.3, Zn 0.3, Co 0.1, I 0.12, Se 0.011; [3] derivate from NRC 1996 Tables; [4] determined by chemical analysis in Tehran University nutrition laboratory

consisted of surgical preparation of the left flank at the level of the stifle and approximately 15 to 20 cm caudo-ventral to the costo-chondral junction of the last rib. All animals were sedated with 30 to 40 mg of xylazine administered intravenously. A tail jack was applied for additional restraint. A 12.5 cm, 16 gauge needle was inserted into the ventral sac of the rumen and an aliquot (5 to 10 ml) of rumen fluid was obtained. Rumen fluid pH was immediately determined using a Model 265A portable pH meter (Orion Research Inc., Beverly, MA). A 5 ml subsample of strained ruminal fluid was mixed with chilled 25% meta-phosphoric acid (H_2PO_4) and stored at $-20°C$ for later determination of VFA. Another 5 ml subsample was mixed with 1% H_2SO_4 and stored at $-20°C$ for later determination of ammonia-N (NH_3N: Gozho and Mutsvangwa, 2008). At the end of the trial, frozen ruminal fluid subsamples were thawed at room temperature and then centrifuged. Ruminal VFA were separated and quantified by gas chromatography (Varian 3700; Varian Specialties Ltd., Brockville, Ontario, Canada) with a 15 m (0.53 mm i.d.) fused silica column (DBFFAP

column; J and W Scientific, Folsom, CA). The ammonia content of ruminal samples was determined using the method described by Weatherburn (1967) modified to use a microtiter plate reader.

Blood samples (about 10 ml) were collected from the jugular vein 3 hours after feeding into tubes containing 12 mg of EDTA, and plasma was separated using high-speed centrifuge (3000 *g* for 20 min at 4°C; Hersom, et al., 2004) and stored at −20°C until analyses. The concentrations of plasma glucose, insulin, triglycerides, NEFA, BHBA, total protein, and plasma urea nitrogen (BUN) were measured using a photometer (Model Clima).

The bulls were weighed monthly and at the end of the experiment before they were slaughtered. They were reweighed again after abdominal fat removal. Also measured were warm carcass weight and subcutaneous fat thickness (with the aid of a caliper). The carcasses were split sagittally, weighed, and chilled overnight at 1°C. The left sides were quartered between the 12th and 13th ribs (Yambayamba et al., 1996). The subcutaneous fat and bone were physically separated from each quarter and the residual (i.e., meat = lean and inter-muscular fat) analyzed for moisture, crude protein, ether extract, and ash.

To determine the amount of undigested grain, one kilogram of feces (based on wet weight) per bull was collected monthly, then washed in a bin with water until the soluble content and fibre particles were removed. The undigested grain particles were gathered using a 0.8 mm sieve, dried in an oven at 60°C for 48 h, and used to estimate the amount of undigested grain based on dry matter of feces.

Statistical analyses

A completely randomized design with 5 treatments (diets) and 5 replicates (bulls) was used for the study. The data for DM intake (DMI), average daily gain (ADG), feed:gain ratio, nutrient digestibility, and undigested grain in feces and ruminal metabolites were analyzed by a mixed model for repeated measurements (Snedecor and Cochran, 1989). Statistical analysis was conducted using SAS 8.2 (SAS, 1996). The mixed model equation for repeated measures was defined as:

$$Y_{ijk} = \mu + T_i + B_j + P_k + (T*P)_{ik} + b_1(IBW) + e_{ijk}$$

where: Y_{ijk} – DMI, ADG, and gain:feed, μ – overall mean, T_i – fixed effect of treatment, B_j – random effect of bulls in treatment, P_k – fixed effect of period, interaction effect between treatment and period, b_1 – regression coefficient of initial body weight (IBW)

as covariate, and e_{ijk} – random error term.

The data for blood metabolites and carcass characteristics were analyzed with GLM procedure of SAS, by using following equation: characteristics were analyzed with the GLM procedure of SAS using the equation:

$$Y_{ij} = \mu + T_i + L_j + e_{ij}$$

where: Y_{ij} – blood metabolites and other variables, μ – overall mean, T_i – fixed effect of treatment, L_j – random effect of cow, and e_{ij} – random error term.

The single degree of freedom orthogonal contrasts for means of equally spaced treatments were linear, quadratic and cubic. Differences were considered to be significant when P < 0.05. Also P > 0.05 and P < 0.10 were considered to indicate a trend toward a significant difference.

Results

Growth and carcass characterization

Data for growth and carcass characteristics are shown in Table 2. DMI were similar for bulls fed with different ratios of barley and maize (average 9.94 kg). No differences were observed for ADG, feed:gain ratio, initial and final body weight (BW) (P > 0.05). There were no differences (P > 0.05) between diets for warm carcass weight (237.6 kg) and ribeye area (79.53 cm²). Quadratic effects were detected for carcass efficiency (ratio of warm carcass weight to calf live weight in the slaughterhouse; Table 2) and were greatest for diets with ratios of 75:25 and 50:50 (barley:maize) compared with the other diets. Back fat thickness and carcass ether extract increased linearly and abdominal fat increased quadratically as the proportion of maize increased in the diets (P < 0.05).

Diet digestibility
and undigested grain in feces

Diet digestibility and undigested grains in feces are shown in Table 3. Diet non-fibre carbohydrate (NFC) digestibility declined quadratically in response to increasing levels of maize (P < 0.05) and was greatest for diets with a ratio of 75:25 (barley:maize). Diet NDF digestibility also increased linearly with increasing levels of maize (P < 0.05). Nonetheless, the overall dietary effects of maize grain on total tract digestibility of DM were not significant. Interestingly, the apparent digestibility of OM for bulls fed diets with ratios

Table 2. Growth performance and carcass characteristics of bulls fed finishing diets based on different proportion of barley to maize grain

Item	Treatment[1]					SEM[2]	Contrast, P<			
	100:00	75:25	50:50	25:75	00:100		linear	quadratic	cubic	quartic
DMI, kg · day^{-1}	9.82	9.80	9.77	10.01	10.08	0.47	0.08	NS3	NS	NS
Initial BW, kg	281	277	274	275	276	4.77	0.69	NS	NS	NS
Final BW, kg	411	407	406	407	409	7.5	0.58	NS	NS	NS
ADG, kg	1.44	1.44	1.47	1.47	1.48	0.07	0.89	NS	NS	NS
F:G	6.81	6.80	6.61	6.88	6.89	0.20	0.67	NS	NS	NS
Warm carcass, kg	236	243	241	235	233	4.66	0.85	NS	NS	NS
Carcass efficiency, %[4]	57.4	59.1	59.0	57.7	57.1	1.01	NS	0.03	NS	NS
Back fat thickness, cm	0.79	0.87	0.88	1.14	1.22	0.06	0.04	NS	NS	NS
Ribeye area, cm^2	79.5	80.3	80.1	79.3	79.0	1.03	0.1	NS	NS	NS
Abdominal fat, %[3]	1.81	1.89	1.97	3.11	2.99	0.04	NS	0.03	NS	NS
Chemical composition of lean between the 12th and 13th ribs, % of DM										
moisture	60.5	60.4	62.2	63.7	63.9	1.09	0.09	NS	NS	NS
crude protein	58.2	58.3	57.7	54.6	55.5	1.51	NS	NS	NS	NS
ether extract	26.7	27.9	28.4	31.3	32.3	0.42	0.04	NS	NS	NS
ash	3.2	3.0	3.3	3.1	2.9	0.04	0.43	NS	NS	NS

[1] ratio of barley to maize grain, respectively. BW – body weight; ADG – average daily gain; DMI – dry matter intake; F : G – feed to gain ratio; [2] standard error of mean; [3] P > 0.10; [4] based on proportion of live weight

Table 3. Diets digestibility (%) and undigested grains in faeces of calves fed finishing diets based on different proportion barley grain to maize grain

Item	Treatment					SEM[2]	Contrast, P<			
	100:0	75:25	50:50	25:75	0:100		linear	quadratic	cubic	quartic
Digestibility coefficient, %										
DM	73.5	73.5	73.8	73.7	73.8	1.11	NS[3]	NS	NS	NS
OM	74.0	74.9	75.1	74.8	74.1	1.13	NS	0.08	NS	NS
CP	78.5	78.3	78.1	77.5	77.0	1.09	0.09	NS	NS	NS
NFC	91.6	92.7	90.1	89.9	86.0	1.15	NS	0.03	NS	NS
NDF	45.9	48.8	48.8	50.3	53.2	1.05	0.04	NS	NS	NS
UGF[4]	7.6	11.9	14.7	20.5	27.6	0.46	0.04	NS	NS	NS

[1] ratio of barley to maize grain, respectively; [2] standard error of mean; [3] P > 0.10; [4,3] UGF – undigested grain in fecal, g · kg^{-1} DM of fecal

of 100:00 and 00:100 barley to maize grain tended to decrease compared with other diets (P = 0.08). When the proportion of maize in diets increased, the amount of undigested grain in feces increased linearly (P < 0.05). Also, when the proportion of maize in diets increased, the apparent digestibility of crude protein (CP) tended to increase (P = 0.09

Characterization of ruminal fermentation

Total and individual VFA concentration. Ruminal VFA concentrations are shown in Table 4. For time 0, there was no significant difference among diets for total and individual VFA concentrations. Three hours after feeding, there were significant differences between diets in the concentrations of total VFA, acetate, propionate, butyrate, and in the acetate:propionate ratio. As the proportion of barley grain decreased in diets, total VFA, propionate, and butyrate concentrations decreased quadratically (Table 4), but the acetate concentration increased quadratically (Table 4). Six hours after feeding, with a decrease in the proportion of barley in the diets, the concentrations of total VFA, acetate, and propionate increased quadratically.

Ruminal fluid pH and ruminal NH$_3$N concentrations are shown in Table 5. For time 0, there were no significant difference between diets in ruminal fluid pH and ruminal NH$_3$N concentrations.

Three hours after feeding, there was a significant difference among diets in ruminal pH and NH$_3$N concentrations. As the proportion of barley grain decreased in the diets, ruminal pH and NH$_3$N concentrations increased quadratically. Six hours after feeding, with decreases in the proportion of barley, ruminal pH exhibited a linear effect and increased from 5.8 to 6.3 when maize totally replaced barley in the diet (Table 5). Also, as the proportion of barley grain decreased, the ruminal NH^{3}N concentration tended to increase (P = 0.09; Table 5).

Plasma metabolites

Plasma metabolites are shown in Table 6. No significant differences were observed in the plasma concentrations of NEFA, BHBA, triglycerides, cholesterol, and total protein (P > 0.05). With decreasing proportions of barley in the diets, the plasma BUN concentration increased quadratically

Table 4. Rumen volatile fatty acid (VFA) concentration of calves fed finishing diets based on different proportion barley to maize grain in 0, 3 and 6 h post feeding

Item	Diet[1]					SEM[2]	Contrast, P<			
	1	2	3	4	5		linear	quadratic	cubic	quartic
Total VFA, Mm										
0 h	71.4	71.5	70.7	71.0	71.5	2.46	NS[3]	NS	NS	NS
3 h	87.9	85.1	83.6	80.1	80.0	2.74	NS	0.03	NS	NS
6 h	81.0	81.2	85.5	85.9	86.3	2.80	NS	0.03	NS	NS
Acetate, mmol · ml⁻¹										
0 h	49.1	49.7	48.1	48.4	48.7	1.32	NS	NS	NS	NS
3 h	52.1	53.2	53.2	55.5	56.8	1.49	NS	0.04	NS	NS
6 h	49.2	50.2	50.3	51.4	52.8	1.47	NS	0.04	NS	NS
Propionate, mmol · ml⁻¹										
0 h	33.8	33.9	33.8	34.4	34.2	0.42	NS	NS	NS	NS
3 h	40.9	40.6	36.4	33.5	33.1	0.44	NS	0.04	NS	NS
6 h	34.6	34.7	36.5	37.8	38.8	0.7	NS	0.04	NS	NS
Butyrate, mmol · ml⁻¹										
0 h	6.4	6.4	6.5	6.2	6.5	0.24	NS	NS	NS	NS
3 h	9.9	9.3	8.4	7.1	7.1	0.28	NS	0.04	NS	NS
6 h	7.6	7.5	8.0	7.9	7.5	0.25	NS	NS	NS	NS
Valerate, mmol · ml⁻¹										
0 h	0.82	0.85	0.87	0.86	0.82	0.02	NS	NS	NS	NS
3 h	1.4	1.3	1.2	1.2	1.2	0.03	NS	NS	NS	NS
6 h	1.1	1.2	1.1	0.96	0.96	0.06	NS	NS	NS	NS
Isovalerate, mmol · ml⁻¹										
0 h	1.2	1.2	1.3	1.3	1.3	0.05	NS	NS	NS	NS
3 h	1.3	1.3	1.3	1.3	1.2	0.06	NS	NS	NS	NS
6 h	1.4	1.2	1.2	1.3	1.2	0.06	NS	NS	NS	NS

[1] diets consisted: 1. 100:00 2. 75:25 3. 50:50 4. 25:75 5. 00:100 ratio of barley to maize grain respectively; [2] standard error of means; [3] P > 0.10

Table 5. Ruminal fluid pH and ammonia nitrogen concentration of calves fed finishing diets based on different proportion barley to maize grain

Item	Diet[1]					SEM[2]	Contrast, P<			
	1	2	3	4	5		linear	quadratic	cubic	quartic
Ph										
0 h	6.3	6.3	6.4	6.4	6.3	0.06	NS[3]	NS	NS	NS
3 h	5.6	5.7	5.7	5.8	6.0	0.05	NS	0.04	NS	NS
6 h	5.8	5.9	6.0	6.2	6.3	0.06	0.03	NS	NS	NS
NH₃ N, mg · dl⁻¹										
0 h	5.1	5.0	4.8	5.0	5.0	0.03	NS	NS	NS	NS
3 h	7.6	7.9	8.2	8.7	8.7	0.02	NS	0.03	NS	NS
6 h	6.8	6.8	7.1	7.2	7.2	0.02	0.09	NS	NS	NS

[1] diets consisted: 1. 100:00 2. 75:25 3. 50:50 4. 25:75 5. 00:100 ratio of barley to maize grain respectively; [2] standard error of means

Table 6. Blood parameters of calves fed finishing diets based on different proportion barley grain to maize grain

Item	Diet[1]					SEM[2]	Contrast, P<			
	1	2	3	4	5		linear	quadratic	cubic	quartic
NEFA, mg · l⁻¹	0.20	0.21	0.21	0.22	0.21	0.02	NS[3]	NS	NS	NS
BHBA, mg · l⁻¹	0.37	0.37	0.38	0.39	0.41	0.05	NS	NS	NS	NS
BUN, mg · l⁻¹	11.0	10.9	11.7	12.9	13.9	0.07	NS	0.03	NS	NS
Glucose, mg · dl⁻¹	82.9	83.8	84.6	85.5	86.4	0.53	0.04	NS	NS	NS
Insulin, mg · dl⁻¹	1.17	1.14	1.13	1.16	1.18	0.02	NS	NS	NS	NS
Triglyceride, mg · dl⁻¹	8.7	8.6	8.6	8.6	8.7	0.06	NS	NS	NS	NS
Cholesterol, mg · dl⁻¹	72.4	75.6	73.0	74.2	75.2	0.92	NS	NS	NS	NS
Total Protein, mg · dl⁻¹	7.7	8.1	8.2	8.3	8.1	0.04	NS	NS	NS	NS

[1] diets consisted: 1. 100:00 2. 75:25 3. 50:50 4. 25:75 5. 00:100 ratio of barley to maize grain respectively: [2] standard error of means [3] P>0.10;

and the plasma glucose concentrations increased linearly; the glucose concentration in bulls fed diets with a ratio of 100:00 barley to maize was lower than in the other diets.

Discussion

Growth and carcass characterization

In agreement with our study, Beauchemin and McGinn (2005) reported that there was no effect of grain source (barley or maize) on the DMI and ADG of heifers. Also Seoane et al. (1990) reported no differences between maize- and barley-based diets on DMI, ADG, and feed efficiency. In contrast, Milner et al. (1995) reported that dry matter intake was 16% greater in steers fed maize grain than in steers fed barley grain, but feed efficiency did not differ between the diets. Overton et al. (1995) used similar proportions of maize to barley (as in our study) in dairy cattle and concluded that increasing the proportion of barley starch in the diet linearly decreased the intake of DM, OM, and starch.

Better carcass efficiency of bulls fed diets with ratios of 75:25 and 50:50 barley to maize in our study resulted from smaller back fat thickness and less abdominal fat with these diets than the other diets. It should be noted that the increased in back fat thickness and abdominal fat coincided with increasing proportions of maize in the diets. In agreement with our results, Miller et al. (1995) reported less abdominal fat in steers fed barley-based diets versus steers fed maize. Also Kincheloe et al. (2003) found greater back fat thickness in steers fed maize than in steers fed barley. But Boss and Bowman (1996) did not find any differences in fat thickness between bulls fed barley or maize.

The increase in the abdominal fat of bulls caused by increasing the proportion of maize grain in the diet may be related to a number of factors, such as a greater level of ether extract and elevated concentration of acetate (a major substrate for lipogenesis in adipose tissues) in the ruminal fluid in these diets. Also, past studies have shown that feeding cows with a greater ratio of maize to barley resulted in elevated passage of starch into the small intestine. Nocek and Tamminga (1991) reported that 80% and 90% of barley starch and wheat starch, respectively, were digested in the rumen, whereas the values for sorghum and maize ranged from 55% to 70%. Thus, relative to barley, a greater proportion of maize starch may reach the small intestine and, subsequently, the large intestine and feces. Reynolds (2006), however, stated that most of the

starch digested in the small intestine could be accounted for as increased glucose absorption into the portal vein and subsequently into the blood stream, as observed in our study. This increase in glucose used by the PDV is due in part to glucose used by omental and mesenteric fat, which can account for as much as 25%, or more, of body fat in dairy cows. Also Flat (1978) found that the rate of fat synthesis is limited when the ATP:ADP ratio becomes excessive. He also reported that lipogenesis requires reducing equivalents (NADH). Metabolic cycles producing NADH generate ATP during the process. More ATP is generated during formation of NADH by some pathways than from others. For example, ATP generation is less in the malate/citrate cleavage cycle than from the pentose phosphate cycle, but ruminant liver and adipose tissues do not employ citrate cleavage unless the glucose supply is enhanced. If an increased supply of glucose from intestinal digestion of starch would permit lipogenesis to occur using the citrate cleavage pathway (as observed in our study), lipogenesis in the total body could be enhanced. Therefore, from the above, it can be inferred that bulls fed diets with ratios of 25:75 and 00:100 barley to maize will deposit more back fat and abdominal fat than with other diets.

In the current study, increases in the proportion of maize in the diets increased carcass ether extract. In contrast, Kincheloe et al. (2003) reported no difference in the carcass marbling score of barley-fed and maize-fed steers. In the late 1960s, classic studies by O'Hea and Leveille (1968) established that glucose and acetate are the main carbon sources for fatty acid synthesis in porcine and ruminant adipose tissues, respectively. Smith and Crouse (1984) contradicted this "dogma" by showing that substrate specificity can differ with depot site, as is the case in intramuscular adipose tissue of beef cattle, where glucose rather than acetate seems to be the primary substrate for fatty acid synthesis.

Diet digestibility and undigested grains in feces

The reduction in the digestibility of NFC as the proportion of maize increased in the diets in our study can be related to the physicochemical characteristics of the maize starch granule. Van Soest (1994) noted that maize grain tends to contain large amounts of prolamins and glutelins, which characterize the insoluble and hydrophobic nature of maize proteins and have a slow rate of hydrolysis in the rumen, whereas oats and barley are high in globulins. Therefore, it is reasonable that when the proportion of maize in a diet increased, the escape

of starch granules into the intestine also increased and some of these granules were excreted in feces. Therefore, it is clear that due to the higher level of undigested grain in feces, the diets with ratios of 25:75 and 00:100 of barley to maize are not economically viable. These results agree with Dion and Seoane (1992) and Boss and Bowman (1996), who found greater apparent starch digestibility in barley-based diets than in those based on maize. In contrast, Kincheloe et al. (2003) and Spicer et al. (1986) reported that starch digestibility in finishing diets did not differ among diets based on maize or barley.

The increases in NDF digestibility in response to increasing levels of maize grain are in agreement with Kincheloe et al. (2003) and Haddad and Nasr, (2007), who found greater apparent digestibility of NDF in maize-based diets than in barley-based ones. Similar results were observed by Kung et al. (1992) and Overton et al. (1995), but Surber and Bowman (1998) reported greater total tract digestibility of DM and CP when steers were fed a barley-based diet compared with a maize based one. In contrast, Kincheloe et al. (2003) reported greater apparent DM and CP digestibilities for maize- than barley-based diets.

Lower ruminal pH and impairment of the action of cellulolytic bacteria as a result of only barley in the diets may have resulted in the lower apparent OM digestibility of diets 1 and 5. In contrast, when maize was the sole source of starch in diet, the escape of starch granules into the intestine increased the chance for greater OM digestion. Therefore, optimum OM digestibility may be achieved by feeding a mixture of barley and maize, especially at a ratio of 75:25 and 50:50 of barley to maize grain.

When maize is the dominant source of starch in the diets, leading to an increase in the escape of starch granules into the intestine, some of these granules could be converted to glucose in the small intestine and then absorbed, resulting in the higher plasma glucose levels with these diets. The remainder of the starch can be fermented in the large intestine or excreted in the feces. Increases in postruminal starch digestion will be accompanied by increases in hindgut fermentation, and subsequent increases in feces protein excretion (Reynolds, 2006). This result can be one of the reasons why diets with higher maize than barley contents tended to have lower apparent digestibility of crude protein (CP). Similarly to our results, Sosin-Bzducha et al. (2010) showed that the fecal starch percentage depended on both the age of calves and the source of starch used. Calves receiving dry maize grain had greater fecal starch losses in successive weeks of age than the other groups receiving barley diets.

Characterization of ruminal fermentation and plasma metabolites

Interestingly, the greater acetate concentration 3 and 6 h after feeding observed with diets having a greater proportion of maize may have resulted in greater carcass fat contents, as acetate is the most important precursor in fat synthesis in ruminant adipose tissues.

Microbial protein synthesis in the rumen depends largely on the availability of carbohydrates and N in the rumen (NRC, 2001). Bacteria are capable of capturing the majority of ammonia that is released in the rumen from AA deamination and the hydrolysis of non-protein nitrogenous compounds. Nevertheless, dietary conditions often occur in which the rate of ammonia release in the rumen exceeds the rate of uptake by ruminal bacteria. Examples of such conditions would include a surplus of RDP or a lack of available energy (Maeng and Baldwin 1976). This asynchronous release of ammonia and energy in the rumen results in inefficient utilization of fermentable substrates and reduced synthesis of microbial crude protein (MCP). Numerous other studies have reported greater MCP passage (in vivo or in continuous culture) when either the NSC level was increased or more degradable carbohydrates were substituted for those less degradable (McCarthy et al., 1989; Stokes et al., 1991). A review of 16 studies indicated that MCP flow to the duodenum was increased by an average of ten percent when slowly degradable sources of starch (e.g., maize) were replaced by more rapidly degraded starch (e.g., barley) (Sauvant and van Milgen, 1995). Similarly in our study, varying the proportion of ruminal degradable starch and protein in our diets by varying the barley:maize ratio influenced rumen microbial fermentation as well as microbial crude protein production. In fact, the concentration of BUN and ruminal NH_3N were lower when diets with higher ratios of barley, especially 00:100 and 75:25 barley to maize, were fed and this may be related to better synchronization between energy and protein sources with these diets than with the other diets.

It should be noted, however, that feeding barley grain as the sole source of starch in diets resulted in decreased ruminal fluid pH for an extended period of time and may have limited the activity of cellulolytic bacteria and NDF digestibility. In agreement with our results, Overton et al. (1995) reported a linear decrease in ruminal pH as the proportion of barley starch increased at the expense of maize starch in the diet of lactating cows. Surber and Bowman (1998) also reported a higher ruminal pH for steers fed

a maize-based diet than for steers fed a barley-based one. In contrast with our results, DePeters and Taylor (1985), Khorasani et al. (1994, 2001), and Casper et al. (1999) reported no differences in ruminal pH between barley-based and maize-based diets.

The higher plasma glucose concentration in bulls fed diets with 25:75 and 0:100 ratios of barley to maize could have resulted from the escape of maize starch into the small intestine and subsequent digestion and absorption into the blood stream (Reynolds, 1998; Harmon and McLeod, 2001). There was no difference, however, between the diets in terms of plasma insulin concentration.

Conclusions

Based on our results, we conclude that feeding bulls finishing diets based on barley-to-maize grain ratios of 25:75 and 00:100 resulted in increased undigested grains in feces, greater subcutaneous fat thickness and abdominal fat. Deposition of fat in the carcass of bulls fed a higher proportion of maize makes it economically unviable and will probably result in financial loss. Feeding barley grain as the sole source of starch resulted in decreased ruminal fluid pH and NDF digestibility. Finally, feeding bulls diets based on ratios of 50:50 and 75:25 barley to maize grain resulted in the best performance because these diets supplied enough energy for rumen microorganisms, and the bulls had better carcass characteristics and ruminal parameters.

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