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Ground versus steam-rolled barley grain for lactating cows: A clarification into conventional beliefs

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ABSTRACT

Our objective was to compare the effects of grinding versus steam-rolling of barley grain at 30 or 35% of diet dry matter on feed intake, chewing behavior, rumen fermentation, and milk production in high-producing lactating cows. Eight multiparous Holstein cows (85 ± 9 d in milk) were used in a replicated 4 × 4 Latin square design experiment with four 21-d periods. Each period included 14 d of adaptation and 7 d of sampling. Treatments included grinding (GB) or steam-rolling (SB) of barley grains at either 35 or 30% of dietary dry matter. Diets were prepared as a total mixed ration and delivered twice daily at 0730 and 1600 h. Neither processing method nor dietary barley grain inclusion rate affected dry matter intake, daily eating, ruminating and chewing times, rumen pH and major volatile fatty acid molar percentages, or milk percentages and yields of fat and protein. Energy-corrected milk yield increased for SB compared with GB at 35% but not at 30% barley grain. Feed efficiency was increased by SB, but was unaffected by dietary barley grain level. Results suggest that at 30% dietary barley grain, GB resulted in similar lactation performance as SB and that SB did not affect productivity when dietary barley grain increased from 30 to 35%. Regardless of barley grain level, grinding effectively maintained dry matter intake and rumen pH at 4 h postfeeding, whereas steam-rolling increased feed efficiency. Increasing barley grain from 30 to 35% of diet dry matter did not improve feed intake and milk production.

Key words: barley grain, grinding, steam-rolling, lactating cow

INTRODUCTION

We have recently demonstrated that steam-rolling offers no digestive and productive advantages over grinding at 26% dietary use of barley grain (*Hordeum* spp.; Sadri et al., 2007). Whole barley grain, rich in highly fermentable starch and protein (Ørskov, 1986; Herrera-Saldana et al., 1990), is not optimally digested by lactating cows (Valentine and Wickes, 1980). As a result, grinding and steam-rolling are commonly used to increase the availability of barley starch and protein to rumen microbes (Mathison, 1996; Yang et al., 2000). Unlike corn and sorghum, barley starch is not extensively integrated with slowly degradable protein matrices and it possesses greater effective DM degradability (e.g., 70 vs. 40%; Herrera-Saldana et al., 1990; Nikkhah et al., 2004). Feeding processed barley grains at high dietary inclusion rates may increase the risk of subacute rumen acidosis (Owens et al., 1997) and asynchronize release of ATP and carbon skeleton and nitrogen compounds (Hall and Huntington, 2008). The elevated rumen VFA release caused by feeding a high amount of barley grain can increase blood insulin and depress milk yield (Ørskov, 1986). As conventionally believed, finely ground grains may depress feed intake by increasing ration dustiness and hastening the ruminal release of organic acids (Morrison, 1935; Mathison, 1996; Nikkhah and Ghorbani, 2003). Grinding, however, is an economical processing technique easily accessible to almost all dairy producers. We intuit that the dietary inclusion rate of barley grain is more critical than processing method for reducing the risk of subacute ruminal acidosis and attaining optimum immune function and economical milk production. Feeding diets with high barley starch and low effective NDF has lowered DMI and rumen pH and compromised immunity (Yang et al., 2000; Emmanuel et al., 2008). Based on rumen in situ studies, treating barley kernel with heat and moisture during the steam-rolling process may reinforce protein–starch and lipid–starch bonds and reduce the initial rumen degradation rate of barley endosperm (Arieli et al., 1995; Mathison, 1996; Ljøkjel et al., 2003a,b; Nikkhah and Ghorbani, 2003). Also, the coarser particles produced by steam-rolling may decrease the degradation rate of barley starch (Fiems et al., 1990; Nikkhah and Ghorbani, 2003; Tothi et al., 2003). However, these considerations have not been

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Table 1. Dry matter-based dietary ingredients at 35 and 30% barley grain

	Dietary use of barley grain	
Ingredient	35%	30%
Alfalfa hay	15.4	15.4
Corn silage	23.0	23.0
Barley grain (ground or steam-rolled)	35.0	30.0
Beet pulp	4.5	9.4
Soybean meal	16.0	16.0
Whole cottonseed	3.9	4.0
NaCl	0.1	0.1
Calcium carbonate	0.2	0.2
Sodium bicarbonate	1.0	1.0
Mineral and vitamin supplement[1]	0.9	0.9

[1]Contained 250,000 IU/kg of vitamin A, 50,000 IU/kg of vitamin D, 1,500 IU/kg of vitamin E, 2.25 g/kg of manganese, 120 g/kg of calcium, 7.7 g/kg of zinc, 20 g/kg of phosphorus, 20.5 g/kg of magnesium, 186 g/kg of sodium, 1.25 g/kg of iron, 3 g/kg of sulfur, 1.25 g/kg of copper, 14 mg/kg of cobalt, 56 mg/kg of iodine, and 10 mg/kg of selenium.

conclusively tested by definitive in vivo comparisons of steam-rolling (**SB**) and grinding (**GB**) of barley grains for high-producing cows. Following our recent data and analogous cow performance on GB versus SB with a 26% dietary inclusion rate of barley grain (Sadri et al., 2007), our objectives were to compare the effects of grinding versus steam-rolling of barley grain at 30 or 35% of dietary DM on DMI; eating, ruminating, and chewing times; rumen fermentation at 4-h postfeeding; and lactation performance of high-producing cows.

MATERIALS AND METHODS

Cows, Treatments, and Experimental Design

Eight multiparous Holstein cows (85 ± 9 DIM; 620 kg of BW; 43 ± 2 kg of milk yield at the commencement of the study, mean ± SE) were used in a duplicated 4 × 4 Latin square design experiment with four 21-d periods. The Latin square was balanced for carry-over effects (Cochran and Cox, 1992). The cow parity was the square, with first- and second-lactation cows separated from older cows. Each period had 14 d of adaptation followed by 7 d of sampling and data collection. Cows were housed in individual free boxes (4 × 4 m) and were allowed 1 h of daily exercise. Treatments were grinding (GB) or steam-rolling (SB) of barley grain at 30 or 35% of dietary DM (Table 1). In increasing the barley grain level from 30 to 35% of diet DM, barley grain replaced beet pulp. All diets were prepared as a TMR with 62% concentrate and 38% forage on a DM basis (Tables 2 and 3). Cows were offered the TMR twice daily at 0730 and 1600 h, permitting 5 to 10% orts with unlimited access to fresh water and salty stones. Diets were formulated with the Cornell-Penn-Miner dairy program (CPM Dairy). The experiment was conducted during spring 2006 at the Dairy Facilities of the Lavark Research Station (Isfahan University of Technology, Iran) under the guidelines of the Iranian Council of Animal Care (1995).

Sampling and Laboratory Analyses

Feeds and Orts. The amount of TMR offered and orts were measured daily from d 15 to 20 of each period to calculate DMI for individual cows. Samples of TMR were taken daily for individual cows during the last 5 d of each period. Feed and ort samples were oven-dried at 60°C for 48 h, ground to pass through a 1-mm screen using a Wiley mill (Arthur H. Thomas Co., Philadelphia, PA), and stored at −20°C until analyzed for chemical composition. Feed samples were analyzed for CP (method 984.13; AOAC, 1990), NDF (Van Soest et al., 1991; using heat-stable α-amylase and sodium sulfite), and ADF (method 973.18; AOAC, 1990). Organic matter was determined by ashing feed and fecal samples for 8 h at 550°C.

Milking and Milk Sampling. Cows were milked 3 times daily at 0330, 1300, and 2130 h. Milk production was recorded at each milking during the final 5 d of each period. The amount of milk produced for each cow at each milking was measured using standard graduated jars (Agri & SD Co., Frankfort, Germany). Before each

Table 2. Chemical composition of forages and diets on a DM basis

	Forage		Dietary barley grain[1]	
Nutrient	Alfalfa hay	Corn silage	35%	30%
DM, %	95.2	24.1	60.0	61.0
CP, %	14.2	8.6	19.0	18.8
NDF, %	43.4	52.0	33.6	35.1
ADF, %	34.2	37.4	19.0	19.0
Starch, %	2.8	26	28.0	25.6
NE_L,[2] Mcal/kg	1.11	1.28	1.54	1.52

[1]DM basis.

[2]Estimated using NRC (2001).

Table 3. Chemical composition of concentrate ingredients (% of DM)

Ingredient	DM	CP	NDF	ADF	Starch	Ether extract
Barley grain	91.0	11.0	20.8	7.2	59.0	2.3
Beet pulp	88.0	10.0	45.8	23.1	5.3	1.0
Whole cottonseed	91.0	23.2	50.3	40.1	3.4	18.5
Soybean meal	89.0	45.1	14.9	9.0	—	1.5

milking cows were monitored for udder inflammation and presence of milk clots in the nipples to ensure that milk yield and composition were not affected by mastitis. No cases of mammary infections were observed during sampling weeks. Milk was sampled 3 times daily at each milking in prelabeled plastic vials, composited for individual cows, preserved with 2-bromo-2-nitropropan and potassium dichromate, and kept at 4°C. Milk samples were analyzed for fat, protein, lactose, and total solids by MilkoScan (134 BN Foss Electric, Hillerød, Denmark).

Rumen Fluid and VFA Analyses. Using 4 cows, rumen fluid from the ventral sac was sampled by using a rumenocentesis technique (Nordlund and Garrett, 1994) 4 h after the morning feeding on the last day of each period. A 16-cm^2 area caudoventral to the costochondral junction of the last rib on a line parallel with the top of the patella was clipped and washed with alcohol. The shaved area was scrubbed with povidone-iodine and sovlorin cetrimide C (1.5% wt/vol chlorohexidine glucoronate and 15% wt/vol cetrimide; Damloron Co., Boroojerd, Iran), and was sedated by injecting 8 mL of 2% lidocaine-epinephrine solution to prevent bleeding. A stainless steel needle was inserted about 4 cm into the ventral sac of the rumen, and a 5-mL syringe was used to aspirate rumen fluid. For 3 d after each sampling, cows were injected intramuscularly with penicillin-G-procaine to minimize any chance of infection. The pH of rumen fluid was measured immediately after sampling using a mobile pH meter (model 137243, Hanna, Lisbon, Portugal). To cease fermentation, 20 μL of 50% sulfuric acid was added to rumen fluids, and samples were kept at −20°C until analyzed for VFA using gas chromatography (0.25 × 0.32, i.d. 0.3 μm, WCOT fused-silica capillary, Chrompack model CP-9002, Vulcanusweg, Delft, the Netherlands) as described by Bal et al. (2000).

Eating, Ruminating, and Chewing Activities. Eating and ruminating activities were monitored visually for a 24-h phase on d 17 of each period. The eating and ruminating activities were recorded once every 5 min under the assumption that each activity would persist for the entire 5 min (Yang et al., 2000). Total time spent chewing was calculated as the time spent eating plus the time spent ruminating. All activities were expressed per kilogram of DM, NDF, and ADF intake (Table 3).

Barley Processing Techniques

Barley grain (*Hordeum* spp.) was ground using a conventional hammer mill (model 5543 GEN, Isfahan Dasht, Isfahan, Iran) with a standard screen size of 1 mm. Barley grains were screened during 2 separate steps and steamed for a minimum of 5 min at 102°C within a 4-m-high stainless steel chamber directly above the rollers (Nikkhah et al., 2004). Steamed grains had a moisture content of 18 to 20% as they were rolled between preheated corrugated rollers (46 × 90 cm, Harris Co., Coalinga, CA). Rolled grains were passed through a channel under air pressure and were allowed to dry before storage and subsequent use in the diet. The steam-rolled barley had a processing index (**PI**) of 72%. The PI was the ratio of density of rolled grains to density of whole grains × 100 (Yang et al., 2000). For instance, if the density of whole and steam-rolled barley grains were on average 580 and 420 g/L, respectively, the PI for steam-rolled barley was (420/580) × 100 or 72.4%.

Statistical Analysis

Data were subjected to Proc Mixed (SAS Institute, 2003). The method of estimating least squares means was REML, and the method of calculating denominator degrees of freedom was Kenward-Roger (SAS Institute, 2003). The model included fixed effects of processing technique, barley grain inclusion rate, their interaction and square, plus random effects of period and cow within square. The model for rumen data included the fixed effects of processing method, barley grain percentage, and their interaction. Normality of distribution and homogeneity of residuals variance were tested using Proc Univariate (SAS Institute, 2003). When significant, the SAS option of PDIFF was used to separate the least squares means. The significant effects were declared at $P < 0.05$ and trends were set at $P \leq 0.10$.

RESULTS AND DISCUSSION

DM and Fiber Intakes

Neither dietary level (35 vs. 30%, $P = 0.24$) nor processing method (ground vs. steam-rolled, $P = 0.36$) of barley grain affected DMI (Table 3). Cows on GB and SB consumed 37.3 and 37.9 Mcal of NE_L daily, respectively. Similar DMI data were consistent with our recent data (Sadri et al., 2007) using mid-lactation cows fed 26% ground, dry-rolled, or steam-rolled barley grain. Results suggest that even at high inclusion rates of barley grain, grinding maintains DMI compared with steam-rolling. The conventional belief that fine grinding produces dust, overly increases rumen fermentation rate, and depresses feed intake (Morrison, 1935; Mathison, 1996), has been based mainly on results from beef studies. Despite greater DMI of lactating cows compared with finishing beef cattle, dairy diets have much greater proportions of dry and ensiled roughages and lower percentages of concentrate. Such differences will alter the physical properties of the ration. Thus, extending the above notion to dairy diets and lactating cows requires caution and clarification. In the current study, barley grain increased in the diet at the expense of beet pulp, which is comparable to barley grain in CP content (10 vs. 11%) and is rich in highly fermentable pectin and slowly degradable fiber (NRC, 2001; Table 3). The beet pulp replacement warrants consideration in interpreting DMI and productive response to dietary inclusion rate of barley grain (30 vs. 35%). Recently, McGregor et al. (2007) reported no effects of feeding either finely (PI = 69%) or coarsely (PI = 83%) steam-rolled barley grain on DMI of mid and late lactation cows. In feedlot cattle, DMI was unaffected when dry-rolled, steam-rolled, or whole barley grains were fed (Owens et al., 1997). In another beef study (Zinn, 1993), coarse barley flakes did not affect DMI, whereas thin flakes tended to increase DMI. High-producing cows consume energy at much higher levels than do beef cattle; thus, comparing beef and dairy studies regarding treatment effects on DMI and rumen fermentation requires careful consideration of the differences in animal energetics. The DMI data alongside similar dietary NE_L and CP concentrations for GB versus SB suggest that the potency of chemical constraints (e.g., rumen VFA; Allen, 2000) on short-term feed intake regulation were likely not different for GB compared with SB.

Eating, Ruminating, and Chewing Times

Eating time, whether daily (343.5 vs. 346.4 min) or per kilogram of intake of DM (13.9 vs. 14.2 min), NDF (34.9 vs. 35.5 min), and ADF (62.5 vs. 64.9 min), was not affected by grinding versus steam-rolling of barley grain ($P > 0.10$, Table 4), which agrees with comparable feed intake among treatments. Likewise, across barley grain inclusion rates, daily ruminating time (476.1 vs. 456.8 min) and rumination per kilogram of intake of DM (19.3 vs. 18.7 min), NDF (48.4 vs. 46.2 min), and ADF (87.4 vs. 84.0 min) were not influenced by GB versus SB ($P > 0.10$, Table 4). These similarities can be attributed to the comparable feed intake and daily ruminating time. The ruminating time (13 to 14 min/kg of DMI) agrees with other reports (Beauchemin et al., 2000; Maekawa et al., 2002). Considering the lower DMI in those studies compared with the present study (e.g., 17 to 21 kg vs. 24.8 kg), we suggest that higher producing cows can consume more DM than lower producing cows mainly by spending more time eating, not necessarily by eating more quickly. Compared with an increased eating time, an increased eating rate is more likely to compromise rumen environment during larger meals, particularly shortly after feeding. Because of the unchanged eating and ruminating times, total chewing time daily and per kilogram of nutrient intake were unaffected by processing methods across the 2 barley inclusion rates. However, daily ruminating time was lower ($P = 0.04$) for SB at 30% of dietary DM than for GB at 30% of dietary DM (428.1 vs. 498.6 min/d). As a result, ruminating time per kilogram of DMI tended to be lower ($P = 0.05$) for SB at 30% than for GB at 30% (17.5 vs. 20.0 min/d). In view of the extensive fermentation of barley starch and protein (Herrera-Saldana et al., 1990), it is likely that barley grain particle size did not have a large effect on rumen mat properties. This view is in agreement with the comparable daily rumination time between SB and GB. A tendency ($P = 0.10$) for greater rumination time per kilogram of ADF intake for GB at 30% of dietary DM (91.8 min/d) than for SB at 30% (77.5 kg/d) might reflect prolonged fiber exposure to microbial enzymes for effective digestion. The consistent rumen fiber mat formation took place possibly earlier and was more efficient for SB at 30% than for GB at 30%. The hypothetical reduction in rumen mat formation efficiency for GB at 30% might be because of fine barley particles with high degradation and passage rates (Mertens, 1997).

Rumen Fermentation

Rumen pH and molar percentages of major VFA at 4-h after the morning feed delivery were unaffected by treatments (Table 5). Steam-rolling rather than grinding of barley grain increased ($P < 0.01$) isobutyrate and valerate concentrations, and tended to increase ($P = 0.06$) isovalerate concentration (Table 5). Branched-chain VFA (**BCVFA**) are products of AA metabolism in the rumen and play important roles in microbial energetics (Brockman, 2005). Because of the small contributions of BCVFA to milk production (Brockman, 2005), the effects of BCVFA on milk energy output are not as significant as the effects of major rumen VFA. Rumen data substantiate our previous findings in mid lactation cows at lower dietary inclusion rates of bar-

Table 4. Treatment effects on nutrient intake and eating, ruminating, and chewing times

	Processing method							
	Steam-rolling		Grinding			P-value[1]		
Item	35% barley	30% barley	35% barley	30% barley	SEM	PM	BR	PM × BR
DMI, kg/d	24.3	24.5	24.4	25.2	0.42	0.36	0.24	0.50
NDF intake, kg/d	9.8	9.9	9.5	10.5	0.39	0.45	0.04	0.11
ADF intake, kg/d	5.4	5.5	5.5	5.7	0.22	0.46	0.41	0.79
Eating time								
Min/d	350.4	342.4	342.4	344.5	6.8	0.67	0.67	0.46
Min/kg of DMI	14.5	14.0	14.0	13.9	0.4	0.37	0.46	0.61
Min/kg of NDF intake	36.2	34.9	36.0	33.7	1.0	0.52	0.09	0.66
Min/kg of ADF intake	70.0	62.8	62.4	62.7	2.6	0.37	0.44	0.39
Ruminating time								
Min/d	485.6[ab]	428.1[b]	453.6[ab]	498.6[a]	22.3	0.40	0.79	0.04
Min/kg of DMI	20.0	17.5	18.6	19.9	0.9	0.58	0.55	0.06
Min/kg of NDF intake	49.4	43.0	47.9	48.9	2.7	0.43	0.34	0.19
Min/kg of ADF intake	90.6	77.5	83.1	91.8	5.7	0.56	0.70	0.07
Chewing time[2]								
Min/d	835.9[ab]	769.0[b]	795.9[ab]	843.3[a]	23.8	0.48	0.69	0.03
Min/kg of DMI	34.5	31.5	32.6	33.8	1.1	0.83	0.41	0.06
Min/kg of NDF intake	85.6	77.7	83.8	82.5	3.2	0.63	0.17	0.32
Min/kg of ADF intake	157.6	140.0	145.5	153.9	7.4	0.90	0.54	0.10

[a,b]Within each row, means with different superscripts differ at $P < 0.05$.

[1]PM = processing method; BR = barley grain use.

[2]Sum of eating and ruminating times.

ley grain (Sadri et al., 2007), providing evidence that grinding of barley grain at up to 35% of diet DM does not compromise rumen pH at 4 h after feeding. Rumen conditions were assessed using rumen fluid samples taken at 4 h after feeding when VFA concentrations were expected to be at peak (Stone, 2004). As such, the lack of a treatment difference in rumen pH when VFA molar percentages are at or near maximum fermentation suggests that grinding versus steam-rolling of barley grain at 35 or 30% of diet DM had little effect on rumen fermentation in cows with an average DMI of 24.8 kg/d. To determine longer term effects of barley grain inclusion rate on DMI, rumen acidity, and microbial shifts, larger and continuous herd studies through the entire early lactation are warranted.

Milk Production

Milk yield was not affected by processing method ($P = 0.24$) or dietary inclusion rate of barley grain ($P = 0.38$, Table 6). Milk fat, protein, SNF, and TS percentages and yields were also unaffected by treatments, supporting the results of Sadri et al. (2007). From a rumen health standpoint, these findings suggest that even in high-producing cows, increasing use of barley grain above certain limits (30% in the current study) does not improve milk production. Feeding GB at 30% of diet DM (37.3 kg/d) led to the same ECM as feeding SB at 30% (37.8 kg/d) and SB at 35% (37.5 kg/d), but GB at 35% (34.9 kg/d) decreased ECM compared with other treatments (Table 6). At both levels of barley

Table 5. Treatment effects on rumen fluid pH and VFA molar percentages at 4 h after the morning feed delivery (TMR was delivered twice daily at 0730 and 1600 h)

	Processing method (PM)		Barley use (BR)			P-value		
Item	Steam-rolling	Grinding	35%	30%	SEM	PM	BR	PM × BR
Rumen pH	5.73	5.70	5.74	5.70	0.07	0.73	0.58	0.76
VFA, mol/100 mol								
Acetate	68.3	68.0	67.6	68.6	1.0	0.87	0.44	0.42
Propionate	17.3	19.5	18.9	17.8	0.9	0.13	0.43	0.40
Butyrate	8.8	9.6	9.1	9.3	0.5	0.34	0.86	0.41
Isobutyrate	1.8	0.6	1.0	1.3	0.3	<0.01	0.30	0.70
Valerate	1.5	0.8	1.2	0.14	0.1	<0.001	0.57	0.46
Isovalerate	1.4	0.8	1.1	1.0	0.3	0.06	0.69	0.29
Acetate:propionate	4.0	3.6	3.7	3.9	0.2	0.22	0.45	0.21

Table 6. Treatment effects on milk production and feed efficiency

	Processing method (PM)							
	Steam-rolling		Grinding			*P*-value		
Item	35% barley	30% barley	35% barley	30% barley	SEM	PM	BR[1]	PM × BR
Milk yield, kg/d	38.3	38.8	36.9	38.0	0.8	0.24	0.38	0.72
4% FCM, kg/d	35.4	35.7	33.4	35.3	0.8	0.17	0.19	0.32
ECM, kg/d[2]	37.5[a]	37.8[a]	34.9[b]	37.3[a]	0.9	0.09	0.12	0.23
ECM:DMI	1.54[a]	1.54[a]	1.45[b]	1.47[ab]	0.03	<0.01	0.74	0.70
Milk yield:DMI	1.57[a]	1.58[a]	1.50[b]	1.51[b]	0.02	<0.01	0.89	0.92
Milk fat, %	3.36	3.47	3.38	3.6	0.14	0.89	0.42	0.46
Fat yield, kg/d	1.39	1.35	1.24	1.34	0.04	0.25	0.26	0.33
Milk protein, %	2.87	2.86	2.85	2.87	0.02	0.88	0.97	0.58
Protein yield, kg/d	1.09	1.11	1.04	1.09	0.03	0.16	0.26	0.53
Milk lactose, %	5.47[a]	5.42[ab]	5.45[ab]	5.37[b]	0.03	0.30	0.05	0.78
Lactose yield, kg/d	2.10	2.11	2.02	2.05	0.05	0.21	0.70	0.46
Milk SNF, %	8.54	8.47	8.56	8.45	0.07	0.95	0.20	0.75
SNF yield, kg/d	3.27	3.29	3.16	3.22	0.09	0.32	0.66	0.82
TS, %	12.00	11.95	11.94	12.05	0.10	0.88	0.79	0.40
TS yield, kg/d	4.59	4.63	4.39	4.57	0.11	0.24	0.33	0.51
Milk fat %:protein %	1.21	1.21	1.18	1.26	0.05	0.86	0.47	0.51

[a,b]Within each row, values with different superscripts differ at $P \leq 0.05$.

[1]BR = barley grain use.

[2]Energy-corrected milk calculated as (kg of milk × 0.3246) + (kg of milk fat × 12.96) + (kg of milk protein × 7.04); Jenkins et al. (1998).

grain, SB consistently increased feed efficiency compared with GB ($P < 0.01$), which was a cumulative effect of the numerical increase and decrease in milk yield and DMI, respectively (Table 6). Overall, therefore, treatments had smaller effects on productivity with a more pronounced effect on feed efficiency. The increased feed efficiency by steam-rolling was about 4.7%. Because the average dietary barley grain use was 32.5% on a DM basis, the barley-related improvement in efficiency was about 15%. This means that based on the results of the current study, steam-rolling of barley could be affordable if steam-rolling costs no more than 15% of the cost of grinding. In addition, the greater the difference between milk price and feed cost, the greater the economic magnitude of improved feed efficiency by steam-rolling.

Milk protein percentage ($P = 0.88$) and yield ($P = 0.16$) were not affected by processing techniques. In addition, increasing barley grain use from 30 to 35% of dietary DM did not affect milk protein percentage ($P = 0.97$) or protein yield ($P = 0.26$). We suggest that differently processed barley grains at both the 30 and 35% dietary inclusion rates did not influence microbial protein synthesis, intestinal AA delivery, or mammary AA supply. These data are in accordance with the comparable DMI and rumen VFA data. Feeding barley grain at 35% instead of 30% of the diet DM tended to increase milk lactose percentage ($P = 0.05$). Given the precise statistical analysis and the low standard error, biological interpretation of the 0.04- to 0.05-percentage-unit increase in milk lactose percentage requires caution. Because of the similar milk SNF percentage and yield, TS percentage and yield was similar among treatments. Milk production data provided no basis for the primacy of steam-rolling over grinding at 30% barley grain in the diet, whereas steam-rolling positively affected milk energy output at 35% dietary barley grain.

CONCLUSIONS

Grinding has conventionally been considered a risk to DMI and rumen function, although it is an accessible technique to process barley grain. Steam-rolling is believed to reduce such risks but is more expensive than grinding. When the DM of TMR contained 30% barley grain, grinding resulted in similar feed intake, rumen fermentation at 4 h postfeeding, and milk production compared with steam-rolling. Grinding increased daily ruminating and chewing times at 30% barley grain in the diet. Compared with grinding, steam-rolling of barley increased feed efficiency at both barley inclusion rates and positively affected milk energy output only at the 35% inclusion rate. Increasing barley grain use from 30 to 35% in the diet of high-producing cows did not improve cow performance.

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