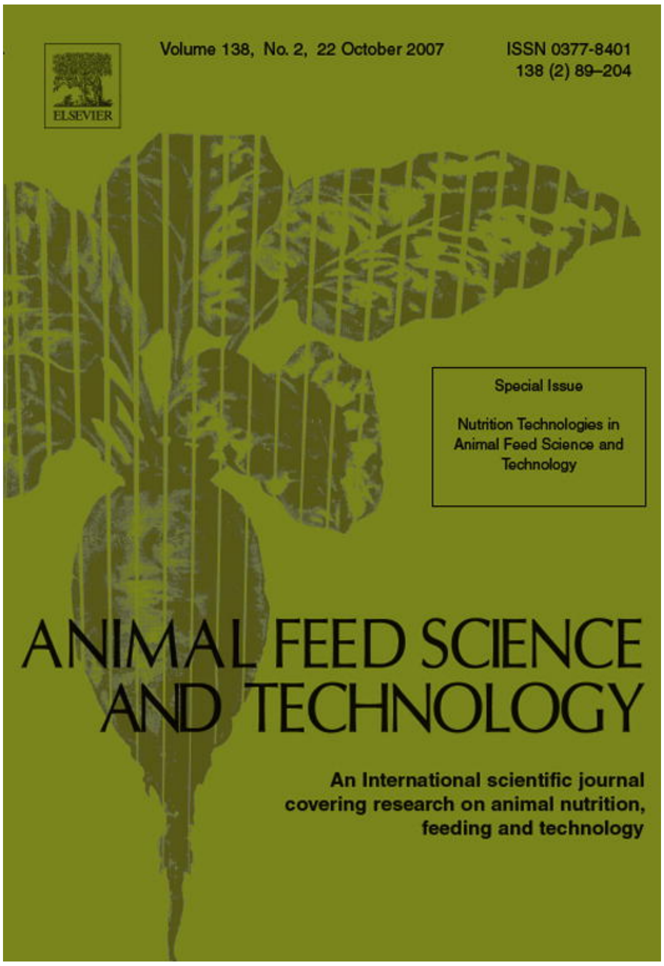
Volume 138, No. 2, 22 October 2007
ISSN 0377-8401
138 (2) 89–204
ELSEVIER
Special Issue
Nutrition Technologies in Animal Feed Science and Technology
ANIMAL FEED SCIENCE AND TECHNOLOGY
An International scientific journal covering research on animal nutrition, feeding and technology

Available online at www.sciencedirect.com
ScienceDirect
Animal Feed Science and Technology
138 (2007) 195–204
ANIMAL FEED SCIENCE AND TECHNOLOGY
www.elsevier.com/locate/anifeedsci

Ground, dry-rolled and steam-processed barley grain for midlactation Holstein cows

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Abstract

Fine grinding of barley grain has traditionally been considered to be a potential risk to rumen function, feed intake and milk yield. These concerns are thought to be reduced by steam-rolling or coarse dry rolling. We hypothesized that finely ground barley grain is as effective in stimulating feed intake and milk production as are dry- and steam-rolled barley grain, and so the objective was to determine effects of feeding either (1) finely ground, (2) steam-rolled, (3) finely dry-rolled, or (4) coarsely dry-rolled barley grain on rumen fermentation, digestibility and milk yield and composition. Eight multiparous midlactation Holstein cows were used in a replicated 4×4 Latin square design experiment with four periods of 21 d. Diets contained 256 g barley grain/kg on a dry matter (DM) basis. Processing method did not affect milk yield and composition, DM intake, rumen pH and volatile fatty acids, fecal and urine pH, and apparent total tract nutrient digestibility. Results suggest that finely ground barley grain is no different than dry-rolled and steam-rolled barley grains in stimulating feed intake and productivity of midlactation cows, when 256 g of dietary DM/kg is barley grain.

Keywords: Barley grain; Dry rolling; Grinding; Holstein; Rumen; Steam rolling

Abbreviations: AIA, acid insoluble ash; CP, crude protein; DB720, dry-rolled barley with PI = 720; DB810, dry-rolled barley with PI = 810; DM, dry matter; EDDM, effective ruminal degradability of DM; EDCP, effective ruminal degradability of CP; GB, finely ground barley grain; PI, processing index; SARA, subacute rumen acidosis; SRB, steam-rolled barley with PI = 680 g/kg; TMR, total mixed ration

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doi:10.1016/j.anifeedsci.2007.06.025

1. Introduction

Barley grain (*Hordeum* spp.) is a major source of ruminally fermentable dry matter (DM; Ørskov, 1986; Zinn, 1993). Grinding, dry rolling, and steam rolling are the most common techniques used to process barley grain because the whole kernel is not effectively digested by non-lactating (Nordin and Campling, 1976) and lactating (Valentine and Wickes, 1980) cows. Rumen degradability of barley grain is higher than maize grain (Herrera-Saldana et al., 1990) because barley starch is not as extensively surrounded by a slowly degradable protein matrix as is maize starch (Theurer, 1986). Given the nature of the endosperm, animal response to processing methods lacks consistency (Hunt, 1996), and highly depends on the dietary inclusion rate of barley grain. We propose that rumen digestion kinetics of barley grain is different at different levels of net energy intake above maintenance. If so, the physical and chemical forms of the barley kernel fed to lactating cows would be of importance, since feeding barley grain at high dietary inclusion rates may increase risks of subacute rumen acidosis (SARA; Owens et al., 1997) and the ruminal asynchrony of energy and N release (Casper et al., 1999).

It is critical that benefits of a processing technique, such as steam rolling, outweigh the costs imposed by equipment establishment and maintenance. The elevated production rate of rumen volatile fatty acids (VFA) due to feeding of finely ground barley grain may cause a surge in circulating insulin, which may subsequently depress milk yield (Ørskov, 1986). As traditionally believed, dietary use of finely ground grains may cause ration dustiness and depress DM intake (Mathison, 1996; Morrison, 1935). Grinding using conventional hammer mills is certainly an easy-to-access technique adopted by large and small dairy holders to process barley grain.

A belief appears to exist, mostly based on ruminal *in situ* studies, that simultaneous use of heat and moisture (e.g., steam rolling) may attenuate unfavourable effects of rapid barley degradation on rumen health and milk yield (Arieli et al., 1995; Mathison, 1996). The much coarser particles of steam-rolled barley (SRB) *versus* ground barley (GB) are thought to reduce ruminal degradation rate of barley starch and N (Fiems et al., 1990; Tothi et al., 2003; Svihus et al., 2005). In addition, prolonged steam-treatment could potentially strengthen the protein– and lipid–starch bonds in barley endosperm, rendering the starch more resistant to microbial fermentation (Ljøkjel et al., 2003a,b). Though critical economically, literature is scarce on *in vivo* comparison of GB and SRB for lactating cows. Additional data are required to assess if feeding SRB instead of GB improves milk yield and composition, and if the improved rumen health and milk yield overshadow costs of purchasing and maintaining steam-rolling equipment. We hypothesized that GB is as effective in stimulating DM intake, and maintaining milk yield and composition in midlactation cows as SRB and dry-rolled (DB) barley grains. The primary objective was to determine effects of feeding finely GB, finely and coarsely DB, or SRB on DM intake, rumen pH and VFA, total tract nutrient digestibility, and milk yield and composition in midlactation Holstein cows.

Table 1
Ingredient and chemical composition of the diets (DM basis)

	g/kg of dietary DM
Ingredient composition	
Alfalfa hay	212.7
Maize silage	212.7
Barley grain	255.9
Whole cottonseed	92.3
Cottonseed meal (mechanically processed)	99.8
Soybean meal (solvent extracted)	111.2
Mineral and vitamin supplement[a]	9.9
Sodium chloride	3.0
Sodium bicarbonate	2.5
Chemical composition	
Crude protein (CP)	161.0
ADF	241.0
aNDF	380.0
NFC[b]	351.0
Ca	6.5
P	5.2
Ether extract	43.1

[a] Contained 196 g Ca, 96 g P, 71 g Na, 19 g Mg, 3 g Fe, 0.3 g Cu, 2 g Mn, 3 g Zn, 100 ppm Co,100 ppm I, 0.1 ppm Se and 50×10^5 IU of vitamin A, 10×10^5 IU of vitamin D and 0.1 g of vitamin E/kg.
[b] Nonfibre carbohydrates = 1000 g DM − [g/kg DM of (aNDF + CP + EE + Ash)].

2. Materials and methods

2.1. Cows and management

Eight multiparous lactating Holstein cows (85 ± 15 d in milk and 32 ± 4 kg/d milk yield) were used in a replicated 4×4 Latin square design experiment. Cows were housed in individual tie-stalls at the Dairy Facilities of the Lavark Research Station (Isfahan University of Technology, Isfahan, Iran) from February to May 2003. The experiment was four periods of 21 d, with the first 14 d of each period for adaptation and the last 7 d for sampling and data collection. Individual stalls (2.17 m × 1.55 m) were equipped with concrete feed bunkers and automatic metal drinkers. Clean wood shavings were used as bedding and refreshed three times daily to minimize the risk of mastitis. Cows were allowed 2 h daily exercise prior to the afternoon milking. Cows were offered a total mixed ration (TMR) thrice daily with forage to concentrate ratio of 43:57 at 07:00, 15:00, and 23:00 h. Dietary ingredients and their chemical composition are in Tables 1 and 2.

The treatments were diets containing (1) finely ground (GB), (2) finely dry-rolled (DB720), (3) coarsely dry-rolled (DB810), and (4) steam-rolled (SRB) barley grains. The processing extent of dry-rolled and steam-rolled grains was expressed by "processing index" (PI; Yang et al., 2000). The PI was the ratio of processed barley grain density to whole barley grain density. Densities of grains were measured in triplicate by weighing a standard volume (2-l glass cylinder) of processed and whole barley grains. An average density was then calculated from the three estimates for each treatment to determine PI. For example,

Table 2
Chemical components of the dietary feed ingredients (g/kg of DM)

	DM	CP	aNDF	ADF	EE	Ca	P
Alfalfa hay	910	150	515	350	25	14.0	2.0
Maize silage	280	88	510	280	38	2.8	2.6
Barley grain	910	117	205	72	22	0.6	3.6
Whole cottonseed	901	235	503	403	193	1.7	6.0
Cottonseed meal	930	260	380	240	45	2.0	11.5
Soybean meal	891	409	140	100	16	3.6	6.5
Vitamin and mineral supplement[a]	990	–	–	–	–	196.0	96.0

[a] Contained 196 g Ca, 96 g P, 71 g Na, 19 g Mg, 3 g Fe, 0.3 g Cu, 2 g Mn, 3 g Zn, 100 ppm Co,100 ppm I, 0.1 ppm Se and 50×10^5 IU of vitamin A, 10×10^5 IU of vitamin D and 0.1 g of vitamin E/kg supplement.

if the density of rolled grains was 420 g/l and the density of whole grains was 600 g/l, the PI calculated was 700 or (420/600) × 1000 g.

2.2. Barley processing techniques

Barley grain was finely ground using a conventional on-farm hammer mill (Isfahan Dasht, model 5543 GEN, Isfahan, Iran) with a standard screen size of 1 mm. Steam rolling was conducted in a commercial feed processing complex (Zyaran Beef Production Co., Qazvin, Iran). For steam rolling, barley grains were screened in two steps, and steamed for approximately 20 min at 102 °C in a stainless steel chamber immediately above the rollers. Steamed grains were subsequently rolled between preheated corrugated rollers (46 cm × 90 cm, Harris Co., Coalinga, CA, USA). The gap between the two rollers was adjusted to produce the desired flake density. Upon rolling, grains were passed through a channel under air pressure and allowed to dry before storage and subsequent use as animal feed. Dry-rolled grains were produced using an on-farm, smooth dry-roller (model no. S1378, Baradaran-E-Shirani Factory, Isfahan, Iran). Initial outputs (about 300 kg) of the rollers by the time of obtaining the desired PI were not used in the experiment. The steam-rolled barley produced had PI of 680. Finely and coarsely dry-rolled barley had PI of 720 and 810, respectively.

2.3. DM intake, feed analyses, and total tract nutrient digestibility

The four total mixed rations (TMR) were offered at rates allowing for 50–100 g/kg orts. Amounts of fresh TMR and orts were recorded daily for individual cows. Daily DM intake was determined by deducting the DM content of the orts from that of the TMR consumed every day of the sampling weeks. Maize silage was sampled daily for the entire experiment to maintain the desired dietary forage:concentrate ratio. Feed and fecal samples were dried at 55 °C for 48 h, ground using a Wiley mill to pass a 1-mm screen (Wiley's pulverizer for laboratory, Ogaw Seiki Co., Ltd., Tokyo, Japan), and stored at −20 °C until later analyses.

All feed samples were analyzed for N (Kjeldahl procedure 988.05; AOAC, 1990), aNDF (using heat-resistant α-amylase without sodium sulfite; Van Soest et al., 1991), ADF (973.18; AOAC, 1990), ether extract (920.39; AOAC, 1990), ash (942.05; AOAC, 1990) and acid insoluble ash (AIA; Van Keulen and Young, 1977). The AIA was used as an internal marker to determine the coefficient of total tract apparent digestibility (CTTAD). The DM, organic matter (OM), and AIA of the fecal samples were also determined using the above procedures.

2.4. Rumen fluid and fecal sampling and analyses

On the last day of each period, a sample of rumen fluid was collected from each cow 4 h after the morning feeding using a stomach tube. The initial 100 ml of fluid aspirated was discarded to minimize saliva contamination. The pH of the second portion was measured immediately using a mobile pH meter (HI 8314 membrane pH meter, Villafranca, Italy). Rumen fluid samples were centrifuged at 900×*g* for 10 min at 4 °C and the supernatants were stored at −20 °C for later volatile fatty acid (VFA) analysis. Grab fecal samples were taken from the rectum every day of the collection period and, after pH measurement, all were frozen for later analysis of AIA. To measure fecal pH, a portion of each fecal sample was thoroughly mixed with the same volume of distilled water to obtain sufficient uniformity and, as a result, a representative pH value. For VFA analysis, 5 ml of rumen fluid was vortexed with 1 ml of 250 g/l meta-phosphoric acid and kept frozen at −20 °C overnight (Erwin et al., 1961). Samples were thawed and centrifuged (Eppendorf AG, 5810R, Hamburg, Germany) at 3000×*g* for 20 min at 4 °C to separate supernatants to read VFA. Concentrations of VFA were determined by GC (0.25×0.32, i.d. of 0.3 μm WCOT Fused Silica Capillary, CHROMPACK CP 9002, model no. CP-9002, serial no. 9477 B, Vulcanusweg 259, 2600 AM, Delft, The Netherlands) using 0.3 ml standard solution of 60 mM crotonic acid.

2.5. Milking and milk composition analysis

Cows were milked thrice daily in a milking parlour at 06:30, 14:30, and 22:30 h with no provision of water or concentrate while milking. During the last 5 d of each period, milk yield was determined for all cows. The amount of milk produced for each cow at each milking was measured using special graduated jars (Agri & SD Co., Frankfurt, Germany). Prior to each 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 different forms of mastitis. Milk was sampled at each milking in pre-labelled 50 ml plastic vials and preserved using potassium dichromate. Milk samples were analyzed for fat, protein and lactose by Milk-O-Scan (134 BN Foss Electric, Hillerod, Denmark).

2.6. Statistical analysis

Data were analyzed with the PROC MIXED of SAS (1999) using the restricted maximum likelihood (REML) estimation method. The effects of treatment (i.e., differently processed barley) and period were fixed and the effect of cow was random. Period was modeled as a repeated factor with first-order autoregressive (AR (1)) covariance structure to account for the correlation of repeated measures on the same cow (Tempelman, 2004). Tukey's test (SAS, 1999) was used to compare least square means, and response criteria were declared different if $P<0.05$. The standard errors (S.E.) reported in the tables are for differences of least square means.

3. Results and discussion

3.1. Apparent total tract DM and OM digestibility, and fecal pH

Physical processing of barley grain did not affect apparent total tract DM and OM digestibility (Table 3), consistent with the comparable lactation performance among treatments. In the study of Tothi et al. (2003), expanded barley grain did not influence total tract starch digestibility compared to GB. Garret et al. (1965, cited by Mathison, 1996), provided the same estimate of NE for SRB and GB in beef cattle. However, steam rolling has been shown (Zinn, 1993) to enhance total tract starch digestibility and NE_m of barley grain compared to dry rolling. For feedlot cattle (Zinn, 1993), despite the same density of dry-rolled and coarse steam-rolled barley grains, starch reactivity (i.e., 4 h incubation with amyloglucosidase) was higher for SRB, which might suggest that barley starch gelatinization, besides particle size, also determines optimum starch utilization by ruminants. However, this suggestion does not appear to be supported by the current study, where the density of SRB was lower than GB, DB720 and DB810 (i.e., particles in SRB were coarse than in GB and DB). However, due to steam treatment, starch was expected to be more gelatinized in SRB than in GB and DB. Thus, we speculate that the lower starch gelatinization in GB and DB, *versus* in SRB, may be compensated by more surface area for microbial attachment in GB and DB *versus* SRB. Hence, starch from SRB, GB and DB may have been utilized to a similar extent in the rumen.

Fecal pH is usually used to assess impacts of processing technique on escape of intact or partially hydrolyzed starch into the hindgut. Higher starch escape to the hindgut allows more extensive hindgut fermentation and higher hindgut acid production, leading to a lower fecal pH. Fecal pH was similar among treatments (Table 3), indicative of equal extent of hindgut fermentation. Beauchemin et al. (2001) also found no differences in fecal pH of lactating cows fed SRB with different densities. Similarly, fecal pH was comparable for steers fed DB and coarse SRB (Zinn, 1993).

Table 3
Fecal and urine pH, and coefficient of apparent total tract digestibility (CTTAD) for dry matter (DM) and organic matter (OM) in cows fed differently processed barley grains.

	Treatment[a]				S.E.	Treatment effect
	GB	SRB	DB720	DB810		P
Fecal DM (g/kg)	167.6	163.1	170.0	171.4	3.2	0.08
Fecal pH	6.63	6.67	6.57	6.66	0.04	0.19
CTTAD						
Dry matter	0.68	0.69	0.66	0.68	0.013	0.36
Organic matter	0.69	0.69	0.67	0.69	0.014	0.36

[a] GB = finely ground barley, SRB = steam-rolled barley with PI = 680, DB720 = dry-rolled barley with PI = 720, DB810 = dry-rolled barley with PI = 810. Processing index (PI) was the ratio of the processed barley grain density to the whole barley grain density multiplied by 1000 (g).

Table 4
Milk production and composition of cows fed diets containing differently processed barley grains

	Treatment[a]				S.E.	Treatment effect
	GB	SRB	DB720	DB810		P
DM intake (kg/d)	23.47	23.89	23.22	23.96	0.66	0.64
Milk yield (kg/d)	27.8	28.6	29.0	26.7	1.2	0.22
Fat yield (kg/d)	1.07	1.07	1.07	0.99	0.04	0.22
Protein yield (kg/d)	0.83	0.85	0.86	0.79	0.03	0.09
Lactose yield (kg/d)	1.42	1.47	1.50	1.37	0.07	0.22
Milk composition						
Fat (g/kg)	39.6	37.8	37.6	38.5	1.5	0.55
Protein (g/kg)	30.2	30.1	30.1	30.2	0.5	0.99
Lactose (g/kg)	51.0	51.4	51.6	51.6	0.5	0.70

[a] GB = finely ground barley, SRB = steam-rolled barley with PI = 680, DB720 = dry-rolled barley with PI = 720, DB810 = dry-rolled barley with PI = 810. Processing index (PI) was the ratio of the processed barley grain density to the whole barley grain density multiplied by 1000 (g).

3.2. DM intake

The DM intake did not differ among treatments (Table 4), indicating no effects of processing technique on diet palatability, and implying a similar impact of differently processed barley grains on short-term feed intake regulation (Allen, 2000). The fine particles of GB clearly had no negative impacts on feed intake in the current study. This finding is not consistent with the traditional belief that finely ground grains produce dust and depress DM intake (Mathison, 1996; Morrison, 1935), but are limited to the conditions of the present study (i.e., dietary level of barley grain of 256 g/kg dietary DM). It is generally believed that the larger particles produced by steam rolling, rather than grinding, may reduce ruminal degradation rate of barley grain (Mathison, 1996) although, unlike rate, extent of barley DM degradation is probably not altered by steam-rolling. The lack of any differences in DM intake of cows fed these barley grains could be interpreted as equal production of fermentation products (e.g., VFA) from DM intake (Allen, 2000). Similarly, DM intake was not affected in feedlot cattle fed dry-rolled, steam-rolled and whole barley grains (Owens et al., 1997), and Bradshaw et al. (1996) also found no impacts of processing method on DM intake in growing and finishing feedlot steers.

3.3. Rumen fermentation

Steam rolling of barley grain is implied to stabilize rumen pH and lower the risk of digestive upsets (e.g., bloat and SARA) by reducing the ruminal starch degradation rate (Mathison, 1996; Tothi et al., 2003). The average rumen pH and VFA molar proportions at 4 h post-feeding were unaltered by feeding these differently processed barley grains (Table 5), probably suggesting only small changes, if any, in the extent and rate of ruminal starch fermentation among treatments. Rumen fluid was sampled at 4 h post-feeding when the highest extent of fermentation, and subsequently the highest VFA levels were expected (Stone, 2004). A lack of effect of decreasing PI on rumen pH has also been reported in beef

Table 5
Ruminal fluid pH and molar proportions of volatile fatty acids (VFA) in cows fed diets containing differently processed barley grains

	Treatment[a]				S.E.	Treatment effect
	GB	SRB	DB720	DB810		P
pH	6.65	6.58	6.60	6.71	0.14	0.81
VFA, mol/100 mol						
Acetate (A)	0.651	0.649	0.668	0.669	0.017	0.53
Propionate (P)	0.202	0.207	0.194	0.183	0.016	0.23
Butyrate	0.111	0.111	0.099	0.106	0.071	0.52
A:P[b]	3.29	3.24	3.56	3.75	0.29	0.31

[a] GB = finely ground barley, SRB = steam-rolled barley with PI = 680, DB720 = dry-rolled barley with PI = 720, DB810 = dry-rolled barley with PI = 810. Processing index (PI) was the ratio of the processed barley grain density to the whole barley grain density multiplied by 1000 (g).
[b] Acetate to propionate ratio.

cattle fed SRB-based diets (Beauchemin et al., 2001; Koenig et al., 2003). Increasing the extent of steam rolling to further expose barley starch to microbial degradation in lactating cows led to a decline in both average and minimum rumen pH (Yang et al., 2001). In another study (Yang et al., 2000), a dramatic decline in the average and minimum rumen pH occurred when PI of SRB decreased from 810 to 720, with no more changes down to PI of 550. The comparable concentrations of rumen VFA at 4 h post-feeding in the present study suggest that rumen fermentation was affected equally by the different physical modifications of barley grain.

3.4. Milk production and composition

Milk yields were not affected by treatments (Table 4), consistent with the similar DM intake, apparent total tract nutrient digestibility, and rumen conditions at 4 h post-feeding among treatments. Yang et al. (2000) reported an increase of 5.2 kg of milk in cows fed medium-flat barley flakes (PI = 640) than in cows fed coarse flakes (PI = 810). The different dietary aNDF levels (380 *versus* 356 g/kg) and inclusion rate of barley grain (256 *versus* 425 g/kg) makes comparison between Yang et al. (2000) and the present study impossible. More importantly, GB was not used by Yang et al. (2000), who only compared SRB with different densities.

The same milk protein content among treatments suggests that dietary inclusion of differently processed barley grains had little impact on rumen microbial protein synthesis and intestinal amino acids (AA) availability, and that AA delivery to the mammary gland was not different among treatments. The milk fat proportion unaffected by treatments seems to rule out the possibility that ruminal digestibility of dietary fibres differed among treatments. The similar concentration of ruminal acetate and equal acetate to propionate ratio among treatments supports the same milk fat response among treatments (Table 4). The comparable milk yield of fat, protein and lactose among GB, DB, and SRB supports Mathison (1996), who found no benefits of SRB over DB for growing-finishing cattle in Western Canada.

4. Conclusions

Grinding is the most accessible conventional method of processing barley grain. Nonetheless, it has long been considered a potential risk to DM intake and the balance between highest starch utilization and increased risk of SARA. While heat treatment (e.g., steam-rolling) is thought to alleviate or attenuate these challenges, no conclusive efforts have been made to clarify the issue by comparing GB and SRB for lactating cows. Our results suggest no differences in DM intake, rumen conditions, total tract digestibility, and milk yield of cows fed finely GB or medium-flat SRB (PI = 680) in a TMR.

Acknowledgements

This study was financed by Isfahan University of Technology (Isfahan, Iran). We sincerely thank the staff at Lavark Research Station (Isfahan University of Technology) for animal care, the management board at Ghiam Dairy Complex (Isfahan, Iran) for dry rolling, and the staff at Zyaran's Feed Processing Unit (Qazvin, Iran) for steam rolling of barley grain.

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