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Effects of Feeding Ground or Steam-Flaked Broom Sorghum and Ground Barley on Performance of Dairy Cows in Midlactation

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ABSTRACT

Ten Holstein cows in midlactation were used in a 5 × 5 replicated Latin square design with 21-d periods to determine the effects of feeding ground or steam-flaked broom sorghum (*Sorghum bicolor*) and ground barley (*Hordeum vulgare* L.) on lactation performance and nutrient digestibility. Diets were fed as total mixed ration and consisted of 46% forage and 54% concentrate (DM basis). Treatment diets included ground barley, ground barley plus ground broom sorghum, ground broom sorghum, ground barley plus steam-flaked broom sorghum, and steam-flaked broom sorghum. Yield of fat-corrected milk was 2.3 kg greater for cows fed diets containing steam-flaked broom sorghum than for cows fed its ground form (24.4 vs 22.1 kg) and was 2.8 kg greater for cows fed diets containing a blend of steam-flaked broom sorghum plus ground barley than for cows fed ground sorghum (24.9 vs 22.1 kg). Yields and percentages of milk fat, protein, SNF, total solids, and apparent digestibility of crude protein were greater for cows fed steam-flaked broom sorghum and ground barley vs. ground broom sorghum. Including steam-flaked rather than ground broom sorghum in diets significantly increased fecal pH (7.10 vs 6.87) and improved efficiency of feed conversion (1.26 vs 1.15). Feeding steam-flaked broom sorghum alone or with ground barley compared with ground sorghum or the blend of ground barley and ground broom sorghum decreased plasma urea nitrogen increased glucose in plasma. Results of this study showed that feeding steam-flaked broom sorghum compared with ground broom sorghum could supply a more efficient source of energy for lactating cows.
(**Key words:** ground barley, lactation, steam-flaked broom sorghum)

Abbreviation key: GB = ground barley, **GS** = ground broom sorghum, **PUN** = plasma urea nitrogen, **SFBS** = steam-flaked broom sorghum.

INTRODUCTION

Cereal grains are the primary source of starch in ruminant diets. Corn (*Zea mays*), barley (*Hordeum* spp.), and sorghum (*Sorghum bicolor*) in North America, barley in Canada, and barley, sorghum, and wheat (*Triticum* spp.) in other parts of the world are traditionally used for human and animal feeds (Huntington, 1997). Sorghum and barley grains contain 72 and 57% starch, respectively, and both provide considerable energy for high-yielding dairy cows (Herrera-Saldana et al., 1990b).

Broom varieties of sorghum (*Sorghum vulgare*) are planted in many parts of Asia and Africa, mainly for broom production but also for use in animal nutrition (Martin et al., 1976). Apparently, there is no documented research about the effects of feeding a broom variety of sorghum on dairy cow performance, which is probably due to the much smaller production of broom sorghum grain relative to grain sorghum.

In a comparative study conducted with 5 cereal grains, it was reported that ruminal digestibility of starch in barley and grain sorghum were 90 and 49%, respectively (Herrera-Saldana et al., 1990b). Indeed, the physical form of starch, its relation to proteins, and the cellular integrity of starch-containing units affect grain availability to microbes and nutrient digestibility (Theurer et al., 1999). Prolamins comprise 50 to 60% of total proteins in sorghum endosperm. Beta and gamma kafirins are major sulfur-hydrogen-containing units that increase the hardness of sorghum grain by making disulfide bonds (El Nour et al., 1998). Tannin, another limiting factor, is relatively abundant in broom sorghum, and it negatively affects ruminal and postruminal digestion of protein, starch, and fiber (Van Soest, 1994). Using moisture, temperature, and pressure coordinately in grain processing consistently increases in vitro enzymatic starch hydrolysis of grains and the proportion of starch digested in the rumen and total gastrointestinal tract (Theurer, 1986; Fredrick et al., 1993). Additionally, synchronization of N and energy supplied by steam-processing decreases ammonia absorption across the rumen wall and improves N recycling to the gastrointestinal tract. These cause higher microbial

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Table 1. Chemical composition of the feed ingredients (% of DM).

Ingredients	DM, %	CP, %	NE_L, Mcal/kg	NDF, %	ADF, %	Ether extract, %	Ca, %	P, %
Corn silage[1]	28.0	9.5	1.60	50.0	28.0	3.8	0.28	0.20
Alfalfa hay	91.0	15.0	1.25	49.5	35.0	2.5	1.40	0.20
Wheat bran	89.0	16.0	1.55	50.5	17.0	4.8	0.13	1.18
Cottonseed meal	93.0	26.0	1.67	38.0	24.0	4.5	0.21	1.15
Barley	88.0	11.7	1.94	19.5	7.5	2.5	0.05	0.38
Broom sorghum	87.0	10.7	1.79	23.5	13.0	3.0	0.12	0.25
Ca-LCFA[2]	99.0					85.0	14.00	
Calcium carbonate	98.0						36.00	
Vitamin and minerals supplement	99.0						19.60	9.60

[1]Urea-enriched silage.

[2]Calcium soaps of long-chain fatty acids.

flows to the duodenum and facilitate starch assimilation in the small intestine and, consequently, improves postabsorptive metabolism of nutrients (Herrera-Saldana and Huber, 1989; Herrera-Saldana, 1990a; O'Mara et al., 1997).

The main purposes of this experiment were to evaluate effects of steam-processing broom sorghum planted in Iran compared with its ground form and with barley and to assess its potential effects on milk yield and composition, digestibility of nutrients, and other productive traits of Holstein cows in midlactation.

MATERIALS AND METHODS

Cows and Management

This study was conducted from December 2000 to March 2001 at Isfahan University of Technology's research farm in central Iran. Ten Holstein cows in midlactation averaging 140 ± 10 DIM, 65 ± 10 d in pregnancy, initial BW of 570 ± 40 kg, and milk yield of 24 ± 2 kg/d were arranged in a replicated 5 × 5 Latin square design. Throughout the experiment, cows were housed in a roofed barn in individual tie stalls (2.17 × 1.55 m) equipped with feed carts and automatic waterers and bedded with wood shavings that were removed 3 times a day and replaced with the new clean materials to reduce humidity of the beds and to keep them more hygienic. Every day before the noon milking, all experimental animals were allowed to walk outdoors for 3 h in the vicinity of their stalls. Five experimental periods consisted of a 14-d adaptation to the diets followed by 7 d for sample collection and data recording. The TMR diets with a forage:concentrate ratio of 46:54 were offered 3 times daily at 0500, 1300, and 2100 h. Diets were fed ad libitum to permit at least 5% orts. Treatment diets included: 1) ground barley (**GB**), 2) GB plus ground broom sorghum (**GS**), 3) GS, 4) GB plus steam-flaked broom sorghum (**SFBS**), and 5) SFBS. Energy and protein content of diets remained as constant as possible when broom sorghum replaced barley to compare 5 treatments in an equal consumption of energy, protein, and main minerals. All needed broom sorghum and barley grains were purchased and prepared once only before starting the experiment and were used for the entire experiment. Broom sorghum grain used in this study is traditionally planted near Myaneh, in Eastern Azarbayjan province in northwest Iran. The chemical composition of all ingredients and the treatment diets are given in Tables 1 and 2.

Cows were milked 3 times daily at 0430, 1230, and 2030 h, and milk yield was measured by reading the predetermined standard values marked on the special jars in the milking parlor just after finishing the milking operation and having milk totally collected in the standard jars separately for each cow and simultaneously for all cows and then recorded in each milking. Feed consumption was measured separately for all experimental cows daily after collecting and weighing orts just before the noon milking, and then drying and determining DM content to calculate the precise amounts of feed intake by subtracting the DM content of orts from that of the daily offered feed. The treatment diets were formulated to meet present recommendations for energy, protein, Ca, and P (NRC, 1989).

Grain Processing

Barley and broom sorghum grains were finely ground by a hammer mill (with a screen size of 2 mm). Additionally, broom sorghum grains were screened to separate from any external materials and steamed for 60 min in a vertical steam chamber (stainless steel) to increase grain moisture up to 18 vs. 13% before processing, and then flaked between preheated large rollers (46 × 90 Flaking Mill, Ferrell-Ross, Amarillo, TX) to a desired flake density (380 to 400 g/L; Santos et al., 1997; Theurer et al., 1999) measured by 3 times by weighing a given volume (2-L glass cylinder) of processed grains.

Table 2. Ingredient and nutrient composition of treatment diets (DM basis).

	Treatment[1]				
Item	GB	GB + GS	GS	GB + SFBS	SFBS
Ingredients (%)					
Alfalfa hay	15.69	15.71	15.71	15.71	15.71
Corn silage	30.89	30.93	30.92	30.92	30.92
Barley	20.38	10.20	…	10.20	…
Broom sorghum	…	10.20	19.44	10.20	19.44
Cottonseed meal	17.24	19.44	20.75	19.44	20.75
Wheat bran	12.17	9.48	8.64	9.48	8.64
Ca-LCFA[2]	0.80	1.20	1.70	1.20	1.70
Sodium bicarbonate	0.59	0.59	0.59	0.59	0.59
Calcium carbonate	1.02	1.02	1.02	1.02	1.02
Minerals and vitamins[3]	0.97	0.97	0.97	0.97	0.97
Salt	0.25	0.25	0.25	0.25	0.25
Chemical composition					
DM, %	71.3	71.3	71.3	71.3	71.3
NE_L, Mcal/kg	1.6	1.6	1. 6	1.6	1.6
CP, % DM	15.0	15.1	15.2	15.1	15.2
EE, %	4.1	4.4	4.8	4.4	4.8
NDF, %	38	38	38.5	38	38.5
ADF, %	21.8	22.7	23.5	22.7	23.5
Tannin, %	…	0.12	0.23	0.11	0.22
NFC, %[4]	37.8	37.2	36.0	37.2	36.0
Ca, %	1.02	1.08	1.15	1.08	1.15
P, %	0.59	0.58	0.58	0.58	0.58

[1]GB = ground barley, GS = ground broom sorghum, SFBS = steam-flaked broom sorghum.

[2]Ca-LCFA = calcium soaps of long-chain fatty acid.

[3]Contained 19.6% Ca, 9.6% P, 7.1% Na, 1.9%Mg, 0.3% Fe, 0.03% Cu, 0.2% Mn, 0.3% Zn, 100 ppm Co,100 ppm I, 0.1 ppm Se, 50×10^5 IU of vitamin A, 10×10^5 IU of vitamin D, and 0.1 g of vitamin E/kg.

[4]Nonfibrous carbohydrate.

All processed grains were dried in a clean, concrete commodity shed, and then transferred to the research farm and stored until mixed with other ingredients in a feed mixer (Tabrizi Machine Mfg. Co., Tehran, Iran).

Sampling and Chemical Analysis

Samples of TMR were collected daily and composited weekly. Feed subsamples were dried at 60°C for 48 h to determine DM content, and the remainder was stored for later analyses. Grab samples of feces were taken from the rectum twice daily at 1000 and 1600 h for the entire 7-d collection period and frozen for later determination of apparent digestibility. Body weights were recorded at the beginning of each period immediately after morning milking following withholding cows from both feed and water for 14 h. Milk samples were collected in each milking and analyzed for fat, protein, lactose, SNF, and TS by Milk-O-Scan (134 BN Foss Electric, Hillerød, Denmark). Yield of 3.2% FCM was calculated by following formula: FCM = 0.454 milk yield + 0.176 fat yield. After finishing 5 experimental periods, fecal samples were placed at room temperature, dried in an oven at 60°C for 72 h, and composited for each period from individual cows. Then all dried samples were ground through 1-mm screen using a Wiley mill and analyzed for N and acid-insoluble ash. Composited feed samples were ground to pass a 1-mm screen for chemical analysis. Samples were analyzed for DM, ash, tannin, and N (AOAC, 1990), and for ADF and NDF (Van Soest and Robertson, 1991). Acid-insoluble ash was used as an internal indigestible marker for determining apparent digestibility of nutrients (Van Keulen and Young, 1977). Urine samples were collected at 1500 h on the last day of each collection period via manual stimulation of the vulva. Samples of ruminal fluid were taken using a stomach tube at 0, 2, 4, and 6 h after the morning feeding on the last day of each period. For avoiding ruminal fluid contamination with saliva, the first 50 ml of the ruminal samples was discarded, and then pH was immediately determined by a mobile and automatic pH meter (HI 8314 membrane pH meter, Hanna Instruments, Padova, Italy).

During the d 6 of each sampling period, blood samples (10 mL) from individual cows were collected from the coccygeal vein with EDTA-treated tubes at 5 h postfeeding. The tubes were immediately centrifuged (for 15 min at $3000 \times g$), and then supernatants were frozen at –20°C until analyzed colorimetrically with a UV-VIS Recording Spectrophotometer (Shimadzu Co., Kyoto, Japan) for glucose and urea N concentrations using the respective kits (AOAC, 1990).

Table 3. Effective degradability of DM and CP in processed grains.

	Treatment[1]					
	GB	GS	GFBS	WSFB	SEM	*P*
Effective degradability of DM, %[2]						
0.05/h	74[a]	43[c]	58[b]	53[b]	1.4	***
0.08/h	70[a]	35[c]	52[b]	47[b]	1.3	***
Effective degradability of CP, %						
0.05/h	70[a]	38.5[b]	33[c]	31[c]	1.1	***
0.08/h	62.8	30.4[b]	24.8[c]	23.7[c]	1.3	***

***$P < 0.001$.

[a,b,c]Column means within row and treatment category with different superscript differ ($P < 0.05$).

[1]GB = ground barley, GS = ground broom sorghum, GFBS = ground steam-flaked broom sorghum, WSFB = whole steam-flaked broom sorghum.

[2]Grain containing nylon bags were incubated ruminally to estimate rate and extent of nutrients degradation.

[3]Ruminal outflow rates (percentage per hour).

In Situ Measurements

Three ruminally cannulated ewes were used to determine ruminal degradability of N and DM of the GB, GS, and SFBS (whole and ground). The procedure involved ruminal incubation of 8 × 12 cm nylon bags with a pore size of 50 μm that contained approximately 3 g of processed grains. Samples were incubated for 0, 2, 4, 8, 16, 24, and 48 h in rumen. After ending incubation times, all bags were rinsed by running tap water until the effluent was clear, and then bags were dried at 55°C for 48 h. Bags and contents were weighed and residues were ground to pass a 1-mm screen and analyzed. Data were fitted to a nonlinear equation to estimate rates and extent of ruminal N and DM degradation (Orskov and McDonald, 1979; Vanzant et al., 1998). The following model was fitted to the percentage of DM disappearance:

$$Y = a + b\,(1 - e^{-c\,t})$$

where a = soluble fraction (%), b = slowly digestible fraction (%), c = fractional rate of disappearance (per hour), and t = time of incubation (h).

Effective ruminal degradability of DM and CP were calculated by the equation:

$$a + b \times c/(c + k),$$

where k = fractional outflow rate. (For more consideration both 0.05/h and 0.08/h were emphasized in this study.)

Statistical Analysis

Data on several variables, including DMI, milk, digestibility, feed efficiency, urine and fecal pH, BW, and blood metabolites were analyzed using the GLM procedure of SAS. The following model was for analysis of data on a replicated 5 × 5 Latin square design:

$$Y_{ijk} = \mu + S_k + R_i\,(k) + C_j\,(k) + T(l) + e_{ijk}\,(l)$$

where μ = mean, S_k = square replicate (k = 1, 2,…s), R_i (k) = period effect within square, C_j (k) = cow effect within square, T(l) = treatment effect (l = 1, 2,…t), e_{ijk} (l) = residual (error).

Because there was no significant interaction of square (parity) and treatment, this effect was eliminated from the model.

Data on ruminal pH were analyzed for only 1 of the squares in a 5 × 5 Latin square design. The observed means were compared by Duncan's new multiple range test.

RESULTS AND DISCUSSION

In Situ Ruminal Digestion Kinetics of DM and CP

The percentage of DM disapearance of the GB and differently processed broom sorghum grains at various rumen incubation times are presented in Table 3. These results show significant differences among the processed grains that were more recognizable for values of 0 h of incubation, as the disappeared fraction of SFBS (especially the ground one) was significantly higher than that of other processed grains. The highest amount of DM disappearance at incubation times of 2, 4, 8, 16, and 24 h were obtained for GB followed by ground SFBS, whole SFBS, and GS. The data shown in Table 3 indicate a dramatic rise in DM disappearance of broom sorghum as a result of steam processing, which was not as much as values for GB, the most quickly degraded treatment in this experiment. Effective degradability

Table 4. Effects of feeding processed grains on apparent digestibility of nutrients.

	Treatment[1]						
Item	GB	GB + GS	GS	GB + SFBS	SFBS	SEM	*P*
Apparent digestibility of							
DM, %	60.9	58.6	58	63	61.4	1.3	NS
OM, %	64.9	60.5	60.1	63.7	63.7	1.2	NS
CP, %	63.7^{ab}	62.4^{bc}	55^{c}	66.7^{a}	64.1^{ab}	1	*

*$P < 0.05$.

^{a,b,c}Column means within row and treatment category with different superscript differ ($P < 0.05$).

[1]GB = ground barley, GS = ground broom sorghum, SFBS = steam-flaked broom sorghum. NS = not significant ($P > 0.05$).

of DM, assuming 2 ruminal outflow rates of 5 and 8%/h, increased dramatically for SFBS vs. GB (58 and 51% vs. 42 and 35%), which can be a consequence of more extensive digestion of partially gelatinized starch in steam-processed grains by rumen microrganisms (Table 4). Steam-processing vs. dry-rolling of sorghum increased effective degradability of DM, NDF, and starch, and finally it enhanced the proportion of ruminally digested OM and cattle performance (Huntington, 1997). Moreover, more undegraded N sources may escape from ruminal degradation due to lessening protein solublity of broom sorghum by heat treatment in presence of water. This exhibited considerable amelioration in nutrient digestibility motivated by starch gelatinization and consequently created a stable condition in rumen during most hours of the day. Evalting some factors such as animal health and milk fat content indicated that there was no detrimental fluctuation in ruminal fermentation through this experiment.

Apparent Digestibility of DM, OM, and CP

Despite no significant difference in apparent digestibility of DM and OM among treatments, coefficients for GB and SFBS or blend of both were numerically higher than values for GS and blend of GS with GB (Table 5). These results were in agreement with previous reports (Plascenia and Zinn, 1996). Undoubtedly, steam-flaking vs. dry-rolling enhances starch digestion in rumen and total gastrointestinal tract by 50 and 30%, respectively (Theurer et al., 1999). Because lower levels of grain were included in the diets of the current

Table 5. Effect of differently processed grains on feed intake, milk production and composition.

	Treatment[1]						
Item	GB	GB + GS	GS	GB + SFBS	SFBS	SEM	*P*
DMI, kg/d	19.1	19.7	19.1	19.6	19.4	0.25	NS
Milk, kg/d	22.6^{ab}	21.4^{c}	21.2^{c}	23.4^{a}	22.6^{ab}	0.5	*
3.2% FCM, kg/d	24.1^{a}	22.2^{b}	22.1^{b}	24.9^{a}	24.4^{a}	0.4	***
FCM:DMI	1.26^{a}	1.12^{b}	1.15^{b}	1.27^{a}	1.26^{a}	0.02	**
Milk fat, %	3.55^{ab}	3.37^{b}	3.44^{b}	3.59^{a}	3.63^{a}	0.04	**
Milk fat, kg/d	0.81^{a}	0.72^{b}	0.73^{b}	0.84^{a}	0.82^{a}	0.01	***
Milk protein, %	3.04^{a}	2.94^{b}	2.95^{b}	2.99^{ab}	3.02^{a}	0.01	*
Milk protein, kg/d	0.68^{a}	0.63^{b}	0.62^{b}	0.70^{a}	0.68^{a}	0.01	**
Efficiency[2]	239^{a}	213^{b}	213^{b}	240^{a}	233^{a}	5	**
Milk lactose, %	4.69	4.72	4.59	4.65	4.64	0.1	NS
Milk lactose, kg/d	1.06	1.01	0.97	1.08	1.05	0.04	NS
Milk SNF, %	8.34^{a}	8.18^{b}	8.17^{b}	8.19^{b}	8.25^{a}	0.03	**
Milk SNF, kg/d	1.89^{ab}	1.75^{c}	1.73^{c}	1.91^{a}	1.87^{ab}	0.04	*
Milk total solids, %	11.88^{a}	11.64^{c}	11.61^{c}	11.78^{ab}	11.86^{a}	0.05	**
Milk total solids, kg/d	2.70^{a}	2.50^{b}	2.47^{b}	2.75^{a}	2.70^{a}	0.05	*

*$P < 0.05$.

**$P < 0.01$.

***$P < 0.001$.

^{a,b}Column means within row and treatment category with different superscript differ ($P < 0.05$).

[1]GB = ground barley, GS = ground broom sorghum, SFBS = steam-flaked broom sorghum.

[2]Milk protein yield (g/d) divided by protein intake (kg/d).

NS = not significant ($P > 0.05$).

Table 6. Effects of feeding processed grains on urine, fecal and ruminal pH, blood metabolites, and BW.

	Treatment[1]						
Item	GB	GB + GS	GS	GB + SFBS	SFBS	SEM	*P*
Ruminal fluid pH	6.6	6.7	6.6	6.6	6.7	0.03	NS
Urine pH	8.12	8.15	8.16	8.17	8.18	0.03	NS
Fecal pH	7.01^{ab}	6.93^{bc}	6.87^{c}	7.17^{a}	7.1^{a}	0.04	**
Plasma glucose, mg/dl	56.0^{bc}	55.0^{c}	55.0^{c}	58.0^{b}	61.0^{a}	0.6	**
PUN, mg/dl[2]	14.3^{c}	16.0^{b}	18.0^{a}	13.4^{d}	14.8^{c}	0.3	**
BW	587	588	590	592	591	3	NS

**$P < 0.01$.

^{a,b,c}Column means within row and treatment category with different superscript differ ($P < 0.05$).

[1]GB = ground barley, GS = ground broom sorghum, SFBS = steam-flaked broom sorghum.

[2]PUN = plasma urea nitrogen. NS = not significant. ($P > 0.05$).

study than those of previous studies, negative effects of intact or partially hydrolyzed starch reached to small intestine may have not been completely manifested. Apparent digestibility of CP was positively affected by steam-processing broom sorghum ($P < 0.05$). The reason for this improvement might have been a synchronous supply of carbohydrate and protein fractions for efficient synthesis of bacterial protein in rumen (Simas et al., 1997, 1998). It appears that the inappropriate impact of tannin might have been partly offset by steam-flaking rather than grinding of broom sorghum.

Milk Yield and Composition

Milk yield was increased ($P < 0.05$) for cows fed GB with SFBS compared with cows fed GS alone or a blend of GB and GS. Feeding SFBS rather than GS increased milk yield by 1.4 kg/d. According to previous reports (Oliveira et al., 1993; Joy et al., 1997; Santos et al., 1997), there was a higher availability of starch resulting from feeding steam-processed grain sorghum because it provided more VFA, particularly propionic acid, and also the microbial mass required by high-producing cows, and it also improved nutrient uptake by the mammary gland.

In this regard, synchronizing of the nutrient supply in the rumen, possibly due to feeding a blend of SFBS with GB, may meet microbial needs for readily fermentable carbohydrate and consequently promote bacterial growth by providing a gradual and efficient digestion of nutrients in SFBS (which can be noticed indirectly according to in situ data). Therefore, decreasing milk yield for cows fed GS can be related to less efficient ruminal fermentation and probably to impaired production of microbial yields. Fat-corrected milk yield was also increased for cows fed either SFBS or GB compared with cows fed diets containing GS ($P < 0.001$), and it was even higher when cows were fed a blend of GB with SFBS. Indeed, by reducing escaped starch to the duodenum, SFBS could supply more energy available for productive objects (Huntington, 1997).

Milk fat (concentration and yield) was higher for cows fed GB and SFBS than for cows fed GS ($P < 0.01$). Tannins, an inhibiting factor for fiber and protein digestion in the rumen, might have decreased VFA production and subsequently led to a decline in milk yield and milk fat content of cows fed GS compared with those fed SFBS and GB. Probably because the quantity of NDF across our diets was higher than the level suggested by NRC to maintain a normal ruminal function (1989), positive effects of higher NDF and ADF on milk fat content did not appear in GS diets. Steam flaking broom sorghum produced lighter feed and, as a result, it might have stimulated both rumination and salivation

Table 7. Ruminal DM disappearance (%) of processed grains at different times of incubation.

	Incubation hours					
Grains	24.0	16.0	8.0	4.0	2.0	0.0
Ground barley	85.54^{a}	79.92^{a}	74.83^{a}	69.28^{a}	52.89^{a}	13.60^{b}
Ground broom sorghum	49.71^{d}	43.85^{c}	37.05^{c}	21.05^{d}	17.15^{c}	13.98^{b}
Steam-flaked broom sorghum (ground)	70.96^{b}	60.96^{b}	51.24^{b}	42.67^{b}	33.32^{b}	21.01^{a}
Steam-flaked broom sorghum (whole)	62.67^{c}	58.36^{b}	47.52^{b}	38.52^{c}	29.17^{b}	13.00^{b}
SEM	2.04	1.19	2.20	1.05	2.10	0.68

^{a,b,c,d}Means within columns followed by different letters differ, $P < 0.0001$.

followed by an efficient digestion process of fiber and starch in a more stable rumen environment.

Milk protein percentages and yields are given in Table 6. Feeding GS and SFBS relative to GS improved ($P < 0.01$) protein content of milk and daily yield of protein by 0.07% and 60 g/d, respectively. The importance of a synchronous supply of energy and protein for obtaining ideal fermentation pathways and microbial growth has been demonstrated by other studies (Herrera-Saldana et al., 1990a; Shabi et al., 1998). Perhaps because of a lower rate and extent of digestibility caused possibly by asynchronous fermentation, feeding GS alone, or even with GB, decreased milk protein, likely via elevating maintenance requirements of microbes. In other words, it can be predicted that tannin increased the ruminal outflow rate and subsequently inhibited efficient N utilization by binding dietary protein in cows fed GS. Therefore, intestinal availability of AA for absorption and metabolism could be limited (Van Soest, 1994).

According to the results obtained from the in situ experiment, it can be also taken into consideration that GB provides more readily fermentable energy during first hours of postfeeding than GS, and it may partially promote microbial growth. Because cows used in this study were not in negative energy and protein balance, the synthesis of microbial protein was probably adequate to meet productive requirements regardless of how much undegradable protein reached the duodenum. Following feeding of SFBS and GB either separately or together, milk protein yield was considerably improved ($P < 0.01$; Table 6) compared with GS or a blend of GB and GS. Although no significant difference in milk lactose was observed between cows fed differently processed grains, SNF content of milk increased significantly when cows were fed SFBS or GB compared with GS. Yield of SNF was higher for cows fed GB with SFBS, but it was lower for those fed GS ($P < 0.05$). However, in previous studies, SNF content of milk had not been altered considerably, so perhaps this was due to the lower content of tannin in grain sorghum than in broom sorghum (0.2 to 0.4% vs 1.2%). Average contents of milk TS were 11.88, 11.64, 11.61, 11.78, and 11.86% for the diets based on GB, GB with GS, GS, GB with SFBS, and SFBS, respectively ($P < 0.01$).

Feed Intake and Efficiency

Feed intake was similar for all diets (Table 3). Some reports have shown lower palatability of high-tannin sorghum than other grains (Rooney and Pflugfelder, 1986; Nocek and Russell, 1988), but that was not observed in this experiment with broom sorghum containing 1.2% tannin. However, DMI declined in some experiments following feeding steam-flaked sorghum (Santos et al., 1997a,b). In this study, steam-processing broom sorghum compared with grinding resulted in a 90 g lower feed intake for each kilogram of 3.2% FCM produced. Efficiency of FCM yield was 1.26, 1.12, 1.15, 1.27, and 1.26. for cows fed GB, a blend of GB and GS, GS, a blend of GB and SFBS, and SFBS, respectively ($P < 0.01$; Table 6). Because feed intake was similar for all diets in this experiment, improved efficiency of milk yield may only be related to higher milk production.

The pH of Ruminal Fluid, Urine, and Feces

Treatment diets did not alter mean ruminal pH, but minimum pH soon after feeding was slightly lower for GB than for other treatments in our study (Table 7). Because flake density of processed sorghum was within recommended range (360 to 437 g/L; Santos et al., 1997; Theurer et al., 1999), no marked change observed in ruminal pH. However, feeding low-density, steam-flaked grains reduced ruminal pH and milk fat content in 2 studies (Yu et al., 1998; Santos et al., 1999).

Mean fecal pH values for cows fed SFBS and blended SFBS with GB (7.10 and 7.17) were significantly higher than for cows fed GS and blended GB with GS (6.87 and 6.93). Fecal pH for cows fed only GB was intermediate (7.1). Escaping high amounts of incompletely digested starch to the hindgut of cows fed low degradable starch from GS may cause low fecal pH in these cows (Chen et al., 1994). In contrast, feeding SFBS with GB may have provided an ideal condition for synchronized nutrient digestion of ingesta in rumen and might consequently have reduced passage of undigested starch to hindgut.

Blood Metabolites and Body Weight

The results of the blood sample analyses are given in Table 7. Cows fed diets based on GS had higher plasma urea concentration than cows fed other treatments ($P < 0.01$). Low digestibility of DM from GS in the rumen was likely responsible for asynchrony between ruminally digested starch and ruminally digested protein, causing low efficiency in capture of ammonia nitrogen in peptide bonds and impairing nitrogen recycling to the gut.

Blood glucose levels were increased in response to feeding either GB or SFBS relative to GS (57 and 61 vs. 55 mg/dL; $P < 0.01$). Synthesis of urea in hepatocytes (urea cycle) requires energy in the form of ATP. Therefore, this can lead to slower rate of gluconeogenesis using major glucogenic products (mainly propionic acid). On the other hand, steam-flaked grains may have supplied adequate propionate to the rumen by more

extensive ruminal fermentation of DM and helped splanchnic tissues to utilize less glucose directly.

Body weight values were similar for all treatments (Table 3). Since DMI and BW gain did not change, it can be concluded that all cows were in similar metabolic situations.

CONCLUSIONS

Selecting highly efficient processing techniques to formulate dairy rations can reduce the risk of ruminal acidosis-related disorders and maximize utilization of DM and CP of resistant products, such as a variety of sorghum grains. Therefore, choosing the best compound of differently processed grains (as with the blend of GB with SFBS in this study) would result in a highly efficient production system. Steam-flaking compared with grinding of broom sorghum improved performance in mid-lactation cows; in particular, milk, FCM, and protein yield paralleled increasing milk fat yield. These may have occurred because of the greater ruminal and total-tract digestion of DM by cows fed SFBS grain, which probably resulted in more efficient recycling of N in the gastrointestinal tract, higher glucose synthesis in liver, and improved uptake of AA by the mammary gland. Steam-flaking rather than grinding broom sorghum grain is more likely to supply sufficient degradable DM in the rumen and to increase performance of dairy cows.

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REFERENCES

AOAC. 1990. Official Methods of Analysis. 15th ed. Assoc. Offic. Anal. Chem., Arlington, VA.

Dewhurst, R. J., D. R. Davies, and R. J. Merry. 2000. Microbial protein supply from the rumen. Anim. Feed Sci. Technol. 85:1–21.

El Nour, N. A., A. D. B. Peruffo, and A. Curioni. 1998. Characterization of sorghum kafirins in relation to their cross-linking behaviour. J. Cereal Sci. 28:197–207.

Fluharty, F. L., and S. C. Loerch. 1989. Chemical treatment of ground corn to limit ruminal starch digestion. Can. J. Anim. Sci. 69:173–180.

Frederick, H. M., B. Theurer, and W. H. Hale. 1993. Effect of moisture, pressure and temperature on enzymatic starch degradation of barley and sorghum grain. J. Dairy Sci. 56:595–601.

Herrera-Saldana, R., R. Gomez-Alarcon, M. Torabi, and J. T. Huber. 1990a. Influence of synchronizing protein and starch degradation in the rumen on nutritive utilization and microbial protein synthesis. J. Dairy Sci. 73:142–148.

Herrera-Saldana, R., and J. L. Huber. 1989. Influence of varying protein and starch intake degradabilities on performance of lactating cows. J. Dairy Sci. 72:1477–1483.

Herrera-Saldana, R. E., J. T. Huber, and M. H. Poore. 1990b. Dry matter, crude protein and starch degradability of five cereal grains. J. Dairy Sci. 73:2386–2393.

Huntington, G. B. 1997. Starch utilization by ruminants: From basis to the bunk. J. Anim. Sci. 75:852–870.

Joy, M. T., E. J. DePeters, J. G. Fadel, and R. A. Zinn. 1997. Effects of corn processing on the site and extent of digestion in lactating cows. J. Dairy Sci. 80:2087–2097.

Martin, J. H., W. H. Leonard, and D. L. Stamp. 1976. Principles of field crop production. In Sorghum. 3th rev ed. Macmillan Pub., New York, NY.

NRC. 1989. Pages 90–110 in Nutrient Requirements of Dairy Cattle. 6th rev. ed. Natl Acad. Sci., Washington, DC.

Oliveira, J. S., J. T. Huber, D. Ben-Ghedalia, R. S. Swingle, C. B. Theurer, and M. Pessarakli. 1993. Influence of sorghum grain processing on site and extent of digestion of starch in lactating dairy cows. J. Dairy Sci. 76:575–581.

O'Mara, F. P., J. J. Murphy, and M. Rath. 1997. The effect of replacing dietary beet pulp with wheat treated with sodium hydroxide, ground wheat, or ground corn in lactating cows. J. Dairy Sci. 80:530–540.

Orskov, E. R., and I. McDonald. 1979. The estimation of protein degradability in the rumen from incubation measurements weighed according to rate of passage. J. Agric. Sci. (Camb.) 92:499–503.

Owens, F. N., D. S. Secrist, W. J. Hill, and D. R. Gill. 1997. The effect of grain source and grain processing on performance of feedlot cattle: A review. J. Anim. Sci. 75:868–879.

Owens, F. N., R. A. Zinn, and Y. K. Kim. 1986. Limits to starch digestion in the ruminant small intestine. J. Anim. Sci. 63:1634–1648.

Plascenia, A., and R. A. Zinn. 1996. Influence of flake density on feeding value of steam-processed corn in diets for lactating cows. J. Anim. Sci. 74:310–316.

Rooney, L. W., and R. L. Pflugfelder. 1986. Factors affecting starch digestibility with special emphasis on sorghum and corn. J. Anim. Sci. 63:1607–1623.

Santos, J. E. P., J. T. Huber, C. B. Theurer, L. G. Nussio, M. Tarazon, and F. A. P. Santos. 1999. Response of lactating dairy cows to steam-flaked sorghum, steam-flaked corn, or steam-rolled corn and protein sources of differing degradability. J. Dairy Sci. 82:728–737.

Santos, F. A. P., J. T. Huber, C. B. Theurer, R. S. Swingle, and J. M. Simas. 1997. Response of lactating cows to various densities of sorghum grain. J. Anim. Sci. 75:1681–1685.

Santos, F. A. P., J. T. Huber, C. B. Theurer, R. S. Swingle, Z. Wu, J. M. Simas, K. H. Chen, S. C. Chan, J. Santos, and E. J. DePeters. 1997. Comparison of barley and sorghum grain processed at different densities for lactating dairy cows. J. Dairy Sci. 80:2098–2103.

Shabi, Z., A. Arieli, I. Bruckental, Y. Aharoni, S. Zamwel, A. Bor, and H. Tagari. 1998. Effect of the synchronization of the degradation of dietary crude protein and organic matter and feeding frequency on ruminal fermentation and flow of digesta in the abomasum of dairy cows. J. Dairy Sci. 81:1991–2000.

Simas, J. M., J. T. Huber, C. B. Theurer, K. H. Chen, S. C. Chan, F. A. P. Santos, and Z. Wu. 1997. Influence of fat source and sorghum grain treatment on performance and digestibilities of high yielding dairy cows. J. Dairy Sci. 80:2907–2912.

Simas, J. M., J. T. Huber, C. B. Theurer, K. H. Chen, S. C. Chan, F. A. P. Santos, and Z. Wu. 1998. Influence of sorghum grain processing on performance and nutrient digestibilities in dairy cows fed varying concentrate of fat. J. Dairy Sci. 81:1966–1971.

Theurer, C. B. 1986. Grain processing effects on starch utilization by ruminants. J. Anim. Sci. 63:1649–1662.

Theurer, C. B., J. T. Huber, A. Delgado-Elorduy, and R. Wanderley. 1999. Invited review: Summary of steam-flaking corn and sorghum grains for lactating dairy cow. J. Dairy Sci. 82:1950–1959.

Van Keulen, V., and B. H. Young. 1977. Evaluation of acid-insoluble ash as natural marker in ruminant digestibility studies. J. Anim. Sci. 26:119–135.

Van Soest, P. J. 1994. Nutritional Ecology of the Ruminant. 2nd ed. Cornell Univ. Press, Ithaca, NY.

Van Soest, P. J., J. B. Robertson, and B. A. Lewis. 1991. Methods of dietary fiber, neutral detergent fiber, and nonstarch polysaccharide in relation to animal nutrition. J. Dairy Sci. 74:3583–3597.

Vanzant, E. S., R. C. Cochran, and E. C. Titgemeyer. 1998. Standardization of in situ techniques for ruminant feedstuff evaluation. J. Anim. Sci. 76:2717–2729.

Wanderely, R. C., J. L. Aquino-Ramos, J. T. Huber, C. M. B. Nussio, M. Pessarakli, and P. V. Morgan. 1996. Digestion kinetics of steam-flaked and dry-rolled sorghum grains and of diets made of 35% processed sorghum in the rumen of lactating cows. J. Dairy Sci. 79(Suppl. 1):211. (Abstr.)

Yu, P., J. T. Huber, F. A. P. Santos, J. M. Simas, and C. B. Theurer. 1998. Effects of ground, steam-flaked, and steam-rolled corn on performance of lactating cows. J. Dairy Sci. 81:777–783.