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EFFECTS OF BARLEY GRAIN PARTICLE SIZE ON DAIRY COW PERFORMANCE

G.R. GHORBANI, A. MORADI-GHAHDERIJANI AND M. ALIKHANI[1]

Department of Animal Science, College of Agriculture, Isfahan University of Technology, I.R. Iran.

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ABSTRACT

Six Holstein cows (120 ± 20 d in milk) were used in a 3 × 3 replicated Latin square design to investigate the effect of different particle sizes of ground barley grain on digestibility, degradation rate and lactation performance. Geometric mean diameters of the barley particles were 0.94, 1.93 and 2.90 mm for treatments 1, 2 and 3, respectively. Diets were only different in barley particle size and all cows received diets containing 40% corn silage and 60% concentrate (DM basis) composed of 50% ground barley. The differences among dry matter intake (DMI), milk fat percentage, milk total solid percentage, daily fat yield, dry matter digestibility, urinary and ruminal pH, daily body weight change, and fecal particle size distribution were not significant. Treatment 3 caused a decrease ($P<0.05$) in milk protein percentage, daily milk yield, and fecal pH compared to treatments 1 and 2; no other treatment differences were significant. With increasing barley particle size, fecal dry matter was increased but daily milk protein yield was decreased ($P<0.05$). Significant differences ($P<0.05$) in 4% FCM, 4% FCM/DMI daily, milk lactose yield, daily total solids yield and organic matter digestibility were observed between treatments 1 and 3. No other treatment effects were observed significant. The soluble fraction, the potential degradable fraction, ruminal degradation rate and the effective degradability of dry matter increased linearly for treatments 1, 2 and 3, respectively. It is concluded that fine grinding of barley (0.94 mm) which is commonly used on dairy farms

1. Associate Professor, former Graduate Student and Assistant Professor, respectively.

improved OM digestibility, milk yield, milk protein percentage and production and would be recommended for feeding conditions similar to those of the present experiment.

Key words: Barley grain, Dairy cows, Holstein, Lactation performance, Milk.

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تاثیر اندازه ذرات دانه جو بر عملکرد گاو شیری

غلامرضا قربانی، اکبر مرادی قهدریجانی ومسعود علیخانی

به ترتیب دانشیار، دانشجوی پیشین کارشناسی ارشد و استادیار گروه علوم دامی، دانشکده کشاورزی، دانشگاه صنعتی اصفهان، اصفهان، جمهوری اسلامی ایران.

چکیده

به منظور بررسی اثر اندازه دانه جو آسیا شده بر عملکرد گاوهای شیری، ۶ گاو شیرده نژاد هولشتین در قالب یک طرح مربع لاتین ۳×۳ تکرار شده، مورد مطالعه قرار گرفتند. قطر متوسط هندسی اندازه ذرات دانه جوبرابر ۰/۹۴، ۱/۹۳ و ۲/۹ میلی متر (به ترتیب در تیمارهای ۱، ۲ و ۳) بود. جیره ها تنها از نظر اندازه ذرات دانه جو با هم تفاوت داشتند و همه گاوها جیره ای دارای ۴۰٪ ذرت سیلو شده و ۶۰٪ کنسانترة دریافت کردند که ۵۰٪ بخش کنسانتره ای جیره را دانه جو آسیا شده (دارای اندازه های مختلف) تشکیل می داد. اختلاف بین ماده خشک مصرفی روزانه، درصد چربی، لاکتوز و کل مواد جامد شیر، تولید چربی روزانه، درصد قابلیت هضم ماده خشک، نسبت تولید روزانه شیر تصحیح شده (بر پایه۴٪ چربی)، ماده خشک قابل هضم، pH ادرار و مایع شکمبه، تغییر وزن روزانه و اندازه ذرات مدفوع، بین تیمارهای آزمایشی معنی دار نبود. با افزایش اندازه

ذرات جو، روندی کاهشی در تولید چربی روزانه و قابلیت هضم ماده خشک و روندی افزایشی در تغییر وزن بدن و اندازه ذرات مدفوع دیده شد. درصد چربی شیر تیمار ۳ بالاتر بود، اما تفاوت بین تیمارها معنی دار نبود. تیمار ۳ به طور معنی داری باعث کاهش درصد پروتئین شیر، تولید شیر روزانه و pH مدفوع شد و با افزایش اندازه ذرات دانه جو، درصد ماده خشک مدفوع به طور معنی داری افزایش و تولید روزانه پروتئین شیر به طور معنی داری کاهش یافت. تولید روزانه شیر تصحیح شده بر پایه ۴٪ چربی، نسبت تولید شیر روزانه تصحیح شده بر پایه ۴٪ چربی به ماده خشک مصرفی روزانه، تولید روزانه لاکتوز شیر، تولید روزانه کل مواد جامد شیر و قابلیت هضم ماده آلی، تفاوت معنی داری بین تیمار ۱ با ۲ و ۲ با ۳ وجود نداشت، ولی بین تیمارهای ۱ با ۳ تفاوت معنی داری دیده شد. افزایش اندازه ذرات دانه جو باعث کاهش مقدار عددی تمام این اندازه گیری ها شد. ناپدید شدن ماده خشک در ساعت های مختلف انکوباسیون نیز با استفاده از گوسفند اندازه گیری شد و تجزیه پذیری موثرماده خشک برای تیمارهای ۱، ۲و ۳ به ترتیب ۷۲/۰۷، ۵۶/۶۳ و ۴۶/۲۶٪ بود که روندی کاهشی را با افزایش اندازه ذرات نشان می دهد. داده های آزمایش نشان می دهد که به احتمال درشت آسیا کردن دانه های جو نیز مشکلاتی را در امر تغذیه دام ایجاد می کند و در شرایط مشابه با آزمایش حاضر، ذرات نزدیک به یک میلی متر را می توان توصیه کرد.

INTRODUCTION

Grain is included in lactating cow diets to support high milk yield (11) and optimization of starch utilization is fundamental to improving yield efficiency of dairy cows. Cattle do not digest whole barley grain efficiently; consequently, barley is usually processed prior to feeding to break the hull and pericarp, thereby promoting access of ruminal microorganisms to the endosperm. Processing increases energy availability of the grain by improving ruminal and total tract starch digestibility (14), which consequently provides more energy in the diet (11). Increased dietary energy density is beneficial because high yielding cows frequently are unable to consume sufficient energy during early lactation.

Grain can be processed to varying extents in order to manipulate degradability of starch (7, 23). Finely ground or steam-flaked grains are more extensively digested in the rumen than rolled or cracked grains (23). Hence, supply of starch for digestion in the small intestine is typically greater when the dietary grain has a larger particle size.

Laksevela (8) examined the significance of fines resulting from grinding a mixture of barley and oat grains and concluded that a medium grind was slightly superior for milk production than a coarse grind. Valentine and Wickes (20) reported that cows fed whole barley grain produced less milk than did cows fed rolled barley.

Increased ruminal degradation of starch may contribute to acidosis and lowered milk fat percentage (13). Barley grain is almost the only starch source for dairy cows in Iran. Barley has a starch content of 55-60% and is much less expensive than corn (25). The main processing method used for barley grain in Iran is grinding. Barley is commonly finely ground (<1mm) and fed to dairy cows. No studies have been conducted to determine the effect of barley particle size that would provide maximum nutrient utilization without depressing lactation performance. The objective of this study was to evaluate the effect of different particle sizes of barley on dairy cow performance.

MATERIALS AND METHODS

Six lactating Holstein cows (120±20 d in milk) producing 27±3 kg d^{-1} of milk were arranged in a duplicated 3 × 3 Latin square design with 20-d periods; days 1-15 for adaptation and days 16-20 for measuring treatment effects. Diets were formulated to contain 40% corn silage and 60% concentrate on a dry matter (DM) basis (Table 1). The diets were formulated to meet National Research Council Recommendations for energy, protein, calcium and phosphorus (12).

The cows were fed *ad-libitum* a total mixed ration (TMR), two times daily in individual stanchions at 0600 and 1400 hr. At each feeding 50% of the feed was offered. They were offered sufficient feed throughout the trial to have 5% feed refusals and feed refusal was recorded. Water was available at all times. Feed consumption was recorded daily and feed samples and orts were collected and composited by week. A portion of each daily sample was dried at 100 °C for determination of dry matter (DM). The remainder was stored for analysis.

Table 1. Ingredients and chemical composition of total mixed diet.

Item	% of DM
Ingredients (%)	
Corn silage	40.0
Barley	27.7
Wheat bran	9.3
Cotton seed meal	19.7
Urea	0.5
Salt	0.2
Sodium bicarbonate	1.0
Calcium carbonate	1.1
Bone meal	0.3
Potassium sulfate	0.2
Chemical composition†	
NE_L, Mcal kg^{-1}	1.62
CP, %	16.04
NDF, %	36.3
ADF, %	19.0
Ash, %	9.0
Ca, %	0.65
P, %	0.5

† Estimated from NRC (12).

Fecal samples were taken at 0800 and 1800 hr from the rectum during each collection period (d 15 to 20), composited by cow, and frozen at -20 °C for later analysis. Body weights were recorded weekly on a common day. In each case, the animals were fasted for 8 h before being weighed.

The cows were milked three times a day (at 05:00 am and 13:00 and 23:00 pm) and total daily milk weights were recorded. Milk samples were collected three times a day during wk three of each period. Milk was analyzed for fat, protein, lactose and solids-not fat (SNF) by Milk-O-Scan

133BN Foss Electric (Hillerod, Denmark). Fat corrected milk (FCM) was evaluated by the formula of Overman and Gaines (16). Composite feed and fecal samples were dried for 72 hr at 55 °C and ground in a cyclone mill (O.S.K. Instruments, Ogawasiki, Japan) to a maximum particle length of approximately 1 mm. Samples were analyzed for DM, ash and N (2). Neutral detergent fiber (NDF), and acid detergent fiber (ADF) were analyzed by the methods of Van Soest (22) and Cherney *et al.* (5). Acid insoluble ash was used as an internal indigestible marker to determine apparent digestibility of dietary fractions (21).

Samples of ruminal fluid were obtained via an esophageal tube; urine was collected by manual stimulation of the vulva and fecal material via the rectum. Ruminal fluid and urine samples were collected from all cows on day 20 and analyzed immediately for pH (Hanna Instruments, Portugal).

Barley grain was sieved through a series of screens with openings of 6.35, 4.75, 3.35, 2.36, 2.00, 1.70, 0.85 and 0.60 mm using a sieve shaker. Geometric mean diameters and standard deviation of feed particles were determined according to the procedure of the American Dairy Science Association (1). Average geometric diameters of barley particles for treatments 1, 2 and 3 were 0.94, 1.93 and 2.90 mm, respectively (Table 2).

Table 2. Characteristics of barley particle size.

	Barley particle size (mm)			
	0.94	1.93	2.90	SEM
Item	DM retention on sieve (%)			
6.35-mm	0	0	0	0
4.75-mm	0	0	0.8	0.39
3.35-mm	0	6.2	23.0	9.9
2.36-mm	2.6	26.7	57.2	21.2
2.0-mm	3.0	14.6	2.6	4.5
1.70-mm	1.4	13.9	1.6	5.2
0.85-mm	48.4	28.4	4.0	18.2
0.60-mm	31.4	3.1	2.6	13.5
Remaining†	13.2	7.1	8.2	2.1
Geometric mean size, mm	0.94	1.93	2.90	0.8
Geometric standard deviation, mm	1.64	1.54	1.32	0.1

†. Barley remained at the bottom.

The ruminal digestive kinetics of processed barley grain was determined *in sacco* by using three ruminally cannulated rams (30 ± 3 kg). Approximately 5 g of each of three average particle size fractions (0.94, 1.93, and 2.9 mm) were weighed into duplicate nylon bags. The 5 × 12 cm bags were measured to have a pore size of 50 mm, sewn with nylon threads. Duplicate bags of each particle size were incubated for 0, 2, 4, 8, 16 and 24 hr in the rumen of each ram. Upon completion of incubation, bags were washed thoroughly under running tap water until the effluent was clear and then were dried at 55 °C for 48 hr. Kinetics of DM disappearance *in situ* was estimated by the nonlinear regression procedure of SAS (19). For each ram and type of feed, the following model was fitted to the percentage of DM disappearance (15):

$$y = a + b(1 - e^{-ct})$$

where

a = soluble fraction (percentage of total)

b = slow digestible fraction (percentage of total)

c = fraction rate of disappearance (per hour)

t = time of incubation (hr).

Effective ruminal degradability of DM (EDDM) was calculated by the following equation:

$$EDDM = a + (b \times c)/(c + k))$$

where k= fractional passage rate (0.06 hr^{-1} was used as the estimated rate of outflow from the rumen).

Data for feed intake, apparent digestibility, yield of milk and milk components were analyzed with the block, cow within lactation period, and ration as the main effects.

The model used to analyze the data was:

$$Y^{ijkl} = \mu + T^i + C^i(s) + P^k(s) + S^i + e^{ijkl}$$

where μ =mean, T^i= rations, C^j = cow effect, P^k =period and S^i= block. The data were analyzed by the least squares method using the General Linear Model Procedure of SAS (19).

RESULTS AND DISCUSSION

For processed barley grain, the soluble fraction, the potential degradable fraction, the ruminal degradation rate and the EDDM were increased as barley particle size decreased (Table 3). Except for potential degradable fraction, Yang *et al.* (25) also found the same increase for processed barley. The dry matter degradability is also in agreement with the nylon bag study of Khorasani *et al.* (7), who demonstrated that reduction of particle sizes of barley from 6 to 2 mm increased the DM degradability. Reduction of the particle sizes form 2.9 to 0.94 mm increased DM digestibility from 55.8% to 60.4% and organic matter (OM) digestibility from 57.9% to 63.1%, even though the difference was only significant ($P<0.05$) for OM (Table 4). The difference in solubility compared to other studies (7, 27) can be attributed to differences in pore size of the bags, the ratio of sample weight, bag surface area, and washing technique used in the studies, although, the difference in EDDM for treatment 1.93 and 2.90 is probably due to their larger size.

Table 3. *In situ* ruminal DM digestion kinetics of barley grain.

	Barley particle size (mm)			
Parameters	0.94	1.93	2.99	SEM
Soluble fraction, % of total	3.55[a†]	2.77[b]	2.27[c]	0.2
Degradable fraction, % of total	83.49[a]	65.1[b]	53.6[c]	5.9
Rate of degradation, % hr^{-1}	29.82[a]	23.28[b]	19.04[c]	1.3
EDDM: (Effective degradable DM, %)	72.2[a]	56.6[b]	46.3[c]	8.9

† Means within a row with the same letters do not differ significantly ($P>0.05$).

The DMI was not different for cows fed barley with different particle sizes even though cows fed fine (0.94 mm) processed barley had higher intake (Table 4). In a study by Zinn (26), DMI was not affected by the degree of barley processing. Yang *et al.* (25) observed a linear increase in DMI by feeding more processed barley to dairy cows. Hironaka *et al.* (6) and Mathison *et al.* (10) observed the opposite. However, in these studies used beef cattle and the diets consisted of 85 to 97% barley. In contrast, the forage represented about 40% of the dietary DM in the present study.

Table 4. Effect of different barley particle sizes on feed intake, milk yield and milk composition.

Item	Barley particle size (mm)			
	0.94	1.93	2.90	SEM
DMI, kg d^{-1}	21.1 [a†]	20.9 [a]	20.6 [a]	1.0
Production, kg d^{-1}				
Total milk	24.3 [a]	23.1 [a]	21.6 [b]	0.52
4% FCM	24.9 [a]	23.5 [ab]	22.6 [b]	0.59
Fat	1.00 [a]	0.95 [a]	0.93 [a]	0.8
Protein	0.78 [a]	0.73 [b]	0.67 [c]	0.03
Milk Composition, %				
Fat	4.2 [a]	4.1 [a]	4.3 [a]	0.8
Protein	3.2 [a]	3.2 [a]	3.1 [b]	0.03
Lactose	4.7 [a]	4.7 [a]	4.7 [a]	1.1
SNF	12.3 [a]	12.2 [a]	12.3 [a]	1.3
Body weight change, kg d^{-1}	-0.02 [a]	+ 0.092 [a]	+0.180 [a]	0.9
Efficiency (FCM/DMI)	1.1 [a]	1.1 [a]	1.2 [b]	0.02

† Means within a row with the same letters do not differ significantly (P>0.05).

The slightly lower DMI of cows fed coarse rolled barley compared with those fed more extensively processed barley was likely due to the combined effects of slightly lower ruminal digestibility and probably lower rate of particulate passage out of the rumen (26). Processing of grain can be important in reducing ruminal pH with consequent depression of fiber digestion (18) but when dietary ingredients are mixed together as done in this study, the effects are partly alleviated.

Larger particle sizes (2.9 mm) significantly decreased (P<0.05) milk production compared with fine and medium size particles (Table 4). The 4% FCM was also significantly (P<0.05) decreased in cows fed coarse barley compared to cows fed fine barley (Table 4), which can be attributed to the decrease in OM digestibility. The results of this study support the findings of Bush (3) who found that cows fed finely ground sorghum grains had higher milk yield than those receiving medium or coarse ground grains. Bush (3) found a positive relationship between particle size of grains and milk yield response. Similarly, Moe *et al.* (11) found that cows fed finely ground corn had higher milk yield than cows fed cracked or whole corn grains.

The importance of appropriately processed barley grain for use in dairy cow diets has been observed by others (4, 8, 2, 26). Laksevela (8) examined the significance of fines resulting from grinding a mixture of barley and oat grain and concluded that a medium grind was slightly superior for milk production than a coarse grind. Valentine and Wickes (21) reported that cows fed whole barley grain produced less milk than cows fed rolled barley, because whole barley was less digestible than processed barley. Yang *et al.* (24) reported that cows fed hull-less barley with a processing index (PI) of 82% produced less milk than cows fed conventional barley with a PI of 68%. In contrast, when the PI of hull-less barley was reduced to 73%, cows fed hull-less barley produced more milk than did cows fed barley.

Improving animal performance by manipulating PI of barley has also been reported for beef cattle. Hironaka *et al.* (6) reported that steam-rolled barley rolled to a medium kernel thickness (PI=82%) resulted in better average daily gain than when thin (PI=74%), coarse (PI=92%), or whole (PI=100%) barley was fed. Similarly, Owens *et al.* (17) reported for feedlot cattle that barley of a medium flake thickness was superior to either barley of thicker or thinner flake for average daily gain, DMI, and feed efficiency.

The milk fat percentage was higher for the coarse diet than for the fine and medium diets but was not significantly different. Fine grinding is often associated with milk fat depression and an increase in milk production in lactating ruminants (14). The percentage and yield of milk protein of cows fed coarse barley was significantly ($P<0.05$) lower than that of those fed fine and medium size barley grains (Table 5). High starch degradability in the rumen increases flow of bacterial CP from the rumen (14), so the increased milk protein yield and percentage found in this study may be related to greater synthesis of ruminal microbial protein (23), or the availability of more propionate for gluconeogenesis (3), thus sparing amino acids for greater synthesis of milk protein. Different particle sizes did not affect the percentage of lactose and SNF in the milk (Table 4). The efficiencies of milk yield (4% FCM/DMI) were different among treatments and cows fed coarse particles were significantly ($P<0.05$) more efficient than those fed fine and medium particles (Table 4). The trend toward improving feed efficiency by using more extensively processed barley is not in agreement with others (6, 10). This improvement was probably due to the lower DMI.

Table 5. Digestibility, and ruminal, urinary and fecal pH of cows fed different particle sizes of barley grain.

	Barley particle size (mm)			
Item	0.94	1.93	2.90	SEM
DM digestibility, %	60.4 [a†]	59.1 [a]	55.8 [a]	6.5
OM digestibility, %	63.1[a]	61.5[ab]	57.9[b]	1.4
Ruminal pH	6.2 [a]	6.2 [a]	6.6 [a]	0.9
Urinary pH	8.1 [a]	8.0 [a]	8.2 [a]	0.4
Fecal pH	7.1 [a]	7.0 [a]	6.8 [a]	0.6
Fecal particle size, mm	0.57 [a]	0.57 [a]	0.64 [a]	0.5
Fecal DM, %	15.4[a]	16.3[b]	17.7[c]	0.1

† Means within a row with the same letters do not differ significantly (P>0.05).

Ruminal pH was not significantly different between treatments but it was 0.5 unit higher for the cows fed 2.9 mm diet (Table 5). Fecal pH was significantly lower ($P<0.05$) for cows fed coarse barley grains compared to other two treatments (Table 5). Fecal pH is largely influenced by the amount of fermentable substrate degraded in the cecum and large intestine and substantial fermentation results in production and absorption of volatile fatty acids (VFA) in the lower tract (18). Wheeler and Noller (24) found a significant negative correlation between fecal pH and fecal starch content. The higher fecal pH of cows fed the fine diet may reflect the smaller concentration of VFA in feces and suggests that less fermentable substrates have reached the lower digestive tract. Ruminal and urinary pH, fecal particle size (Table 5) and changes in body weights (Table 4) did not differ for the three degrees of grain processing. Fecal DM percent was also significantly increased as the size of particles increased (Table 5).

Since processing increases total tract digestion, it usually improves feed efficiency; therefore, for maximum efficiency digestion in the small intestine may be preferred, but processing the feed to increase digestibility of starch reaching the small intestine usually increases ruminal digestion as well (13). Feeding particles in a coarse form to increase flow of particles (starch) to the small intestine appears to be impractical, due to the sacrifice in total tract digestibility of starch as also shown in this study.

CONCLUSIONS

Although there is very limited information concerning the optimal degree of processing of barley grain, the present study and other reports (10, 25) demonstrate that extent of barley processing has an influence on cattle performance. The degree of grinding barley grain affected milk production, 4% FCM, milk protein percentage and yield, efficiency and OM digestibility. Barley that was finely ground (0.94 mm) produced the most milk, because of highest digestibility. Feeding cows coarsely ground barley (2.9 mm) was the least effective, because of low digestibility in total tract. Because in this study long forage was fed, adequate effective fiber was offered, and therefore, extensively ground barley did not produce severe digestive disturbances. It is concluded that optimal grinding of barley grain for dairy cows is a finer grinding, if fed with long forage. Coarse grinding which is recommended to reduce ruminal fermentation rate is not recommended, as the physical barriers limit ruminal digestion as well as digestion in the small intestine.

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