ABSTRACT: We conducted a study to determine the effects of treating barley grain with a fibrolytic enzyme mixture on chewing activities, ruminal fermentation, and total tract digestibility in cattle. We also investigated the potential benefits of using barley straw rather than barley silage as a roughage source in high-grain diets for feedlot cattle. Steers were given ad libitum access to one of four diets that consisted of 95% barley-based concentrate and 5% forage (DM basis). The concentrate was either control or enzyme-treated, and the forage was either barley silage or barley straw. Applying the enzyme mixture onto the barley lowered the concentrations of dietary ADF and NDF. However, it is not certain when this fiber hydrolysis occurred relative to feed consumption because the fiber analyses were conducted after the study was completed. Enzyme treatment of barley increased total tract dietary ADF digestibility by 28% ($P < .05$). Acetate-to-propionate ratio tended to decrease, which suggests that enzymes may have increased ruminal starch digestion as a result of enhanced digestion of barley hulls. Replacing silage with straw increased ADF intake ($P < .05$) and resulted in 1-h/d increase in rumination time ($P < .05$). Even though there was no effect of diet on ruminal pH, replacing silage with straw increased ruminal acetate, as a percentage of total VFA, and total tract ADF digestion ($P < .01$). This study demonstrates that using a fibrolytic enzyme mixture in high-grain diets that contain mainly barley grain can improve fiber digestion and grain utilization, but the mode of action is unclear. Straw can be used rather than silage to increase the effective fiber content of a high-grain feedlot diet.

Key Words: Beef Cattle, Barley, Enzymes, Fiber, Digestion

Introduction

Barley is an important component of ruminant diets. Barley contains approximately 19 to 25% NDF because barley hulls are high in fiber (>70% NDF) and the hulls represent 15 to 20% of the total weight of barley grain DM (Rode and Beauchemin, 1995). Digestibility of barley is limited by the hull fraction. barley hulls are less digestible than barley straw (Hepton et al. 1995). In addition, the hull creates a barrier to microbial digestion by limiting the access of ruminal microbes to the inner, more digestible endosperm (McAllister et al., 1990).

Use of fibrolytic enzyme additives may provide a unique opportunity to increase the digestibility of barley grain. Several studies using enzyme additives in ruminant diets that contained mainly forage have reported improvements in digestibility (Beauchemin et al., 1995; Lewis et al., 1995; Feng et al., 1996). Enzyme mixtures may also be beneficial in high-concentrate diets (Boyles et al. 1992; Beauchemin et al. 1997). Exogenous fibrolytic enzymes may help overcome the depression in fiber digestion that occurs using high-concentrate diets.

Chewing activity, saliva production, and ruminal pH are generally low for cattle fed high-concentrate diets, particularly those that contain barley (Elam, 1976; Beauchemin, 1991). Thus, feedlot finishing diets usually also contain forage fiber. Whole crop barley silage is a commonly used fiber source; however, barley straw may be a more effective source of fiber than barley silage. Replacing barley silage with barley straw adds more NDF of longer physical form to the diet, and this may increase the time spent chewing and the amount of saliva secreted.

The objectives of this study were 1) to determine, for high-concentrate diets offered to feedlot cattle, the
effects of treating barley with fibrolytic enzymes on ruminal and total tract digestibility and 2) to investigate the effects of replacing barley silage with barley straw on chewing activities and digestive traits.

Materials and Methods

The experiment was designed as a 4 × 4 Latin square using four ruminally cannulated steers (initial weight, 465 ± 62 kg). In each period, steers received one of four total mixed rations (TMR) consisting of 95% concentrate and 5% forage (DM basis). The concentrate consisted mainly of tempered, rolled barley grain and was formulated to meet the nutrient requirements for growing cattle (NRC, 1984; Table 1). A 2 × 2 factorial arrangement of treatments was used with the following main effects: two concentrates (control or enzyme-treated) were combined with two forages (barley silage or barley straw). The following four diets were fed: 1) untreated concentrate and barley silage (B-SI); 2) untreated concentrate and barley straw (B-ST); 3) enzyme-treated concentrate and barley silage (B+SI); and 4) enzyme-treated concentrate and barley straw (B+ST).

The enzyme mixture (Pro-Mote®, Biovance Technologies Inc., Omaha, NE) contained mainly cellulase and xylanase activities, with relatively low levels of residual amylase activity. Enzyme activities were measured in our laboratory (pH 5.5; temperature 50°C) as millimoles of reducing sugars per millimoles of enzyme mixture per minute. Enzyme activities were 31.0 for cellulase and 43.4 for xylanase. Glucose and xylose were the reducing sugars measured, and carboxymethyl cellulose and oat spelt xylan were the substrates, for cellulase and xylanase, respectively. Concentrated enzyme mixture was dissolved in water (100 g/L) and then added to barley (15 L/t) during tempering. The barley was tempered by adding 15% water and leaving it overnight. The grain was then rolled and dried. The enzyme-treated grain was prepared on three occasions as needed during the study.

The barley straw was coarsely chopped to an average particle length of 8.7 ± 3.7 cm, determined manually. The barley silage was chopped using a theoretical length of chop of .95 cm, and mean geometric particle size was .5 ± .3 cm, determined by wet-sieving and calculated as described by ASAE (1992). Each diet was fed as a TMR by blending concentrate, forage, and a small amount of molasses (2% of the TMR; DM basis) daily using a feed mixer.

Steers were housed in individual stalls bedded with rubber mats and cared for according to the guidelines of the Canadian Council on Animal Care (Ottawa, ON). Each period consisted of 28 d, which included 10 d of adaptation; 3 d of monitoring ruminal pH, sampling of ruminal fluid, and observing chewing activities; and 7 d of measuring total tract digestion.

Diets were offered ad libitum (115% intake) once daily at 0900. The difference between the quantity of DM offered and the quantity refused from d 11 to 19 (8-d period) was used to calculate the ad libitum DMI for each steer. Each diet was sampled every 2nd d and composited by period. Orts were removed daily, weighed, sampled, and composited by period for each animal. Composite samples of feed and orts were ground to pass a 1-mm screen and retained for chemical analysis. Intakes of NDF and ADF were calculated as the difference between the amount of fiber offered and refused. The ADF content was also used to determine whether the concentrate-to-forage ratio of orts differed from that of the TMR.

Total tract nutrient digestion was measured by total collection of feces. During the last 10 d of each period, the steers were fed for 90% of ad libitum intake. Even though feed refusals were minimal during the collection phase, orts were collected daily and composited by steer for each period. The chemical composition of orts was used to calculate nutrient intakes.

The steers were fitted with harnesses that ensured separation of the urine from feces. Feces were collected and weighed each morning of the last 7 d of the period, and a sample representing 5% of the total weight was frozen at –20°C. The DM content was determined for each sample, but OM, NDF, ADF, CP, and starch analyses were done after the fecal samples were composited by period for each animal.

The DM content of feed, orts, and feces was determined by oven-drying at 55°C, and OM was determined by ashing (AOAC, 1990; method no. 924.05). The NDF content was determined by the method described by Van Soest et al. (1991) using heat-stable amylase, but without using sodium sulfite. The ADF content was determined by method no. 973.18 of AOAC (1990). The CP content (N × 6.25) was determined by flash combustion, chromatographic separation, and thermal conductivity detection (Carlo Erba Instruments, Milan, Italy). Starch was determined by the enzymatic method described by Herrera-Saldana et al. (1990), modified as follows. Sample size and reagents were reduced in order to read

Table 1. Composition of concentrate (DM basis) a

<table>
<thead>
<tr>
<th>Ingredient</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tempered, rolled barley grain</td>
<td>92.66</td>
</tr>
<tr>
<td>Canola meal</td>
<td>4.57</td>
</tr>
<tr>
<td>Urea</td>
<td>.20</td>
</tr>
<tr>
<td>Canola oil</td>
<td>.43</td>
</tr>
<tr>
<td>Limestone</td>
<td>.02</td>
</tr>
<tr>
<td>Trace-mineralized salt b</td>
<td>1.22</td>
</tr>
<tr>
<td>Vitamin premix b</td>
<td>.02</td>
</tr>
</tbody>
</table>

a Mix contained the following: 92.6% NaCl, 1.1% ZnSO4·H2O, 0.94% MnSO4·4H2O, .32% CuSO4·5H2O, .005% CaSO4·6H2O, .0044% Na2SeO3, 200,000 IU of vitamin A/kg, 25,000 IU of vitamin D/kg, and 200 IU of vitamin E/kg.
samples colorimetrically at 490 nm using a microplate reader (Dynatech Laboratories, Chantilly, VA). The enzymatic hydrolysis was extended to 1 h using amylase (Termamyl, Novo Nordisk, Bagsvaerd, Denmark), and amyloglucosidase (no. 208-469, Boehringer Mannheim, Laval, Quebec, Canada) was used rather than glucoamylase. For fecal samples, feces from a sheep that was fed forage was included in the glucose standards (Rode et al., 1996).

Eating and ruminating behaviors were monitored visually for a 24-h period at the same time as pH monitoring. Eating and ruminating activities were noted every 5 min, and each activity was assumed to persist for the entire 5-min interval. A meal was defined as at least one observation of eating activity that would occur after at least 20 min without eating activity. This criterion was similar to the definition of eating used by Wangsness et al. (1976). They defined a meal as at least 1 min of eating activity that would occur after at least 20 min without eating activity. To estimate the time spent eating per kilogram of DMI, the actual intake for that day was used. A period of rumination was defined as at least 5 min of ruminating that would occur after at least 5 min without ruminating activity. When estimating the number of rumination periods per kilogram of DMI, the average daily intake measured in that period was used because time spent ruminating was assumed to reflect the DMI of the previous days. Total time spent chewing was calculated as the total time spent eating and ruminating.

Ruminal pH was measured continuously for 24 h using an industrial electrode (model PHCN-37, Omega Engineering, Stanford, CT) placed in the rumen. The pH meter was connected to a data logger so that records of pH could be obtained every minute and averaged over 15-min intervals. Hours during which pH was either > 6.2 or < 5.8 were calculated. The lowest pH for each steer over the entire period was recorded.

Ruminal fluid samples were collected at 0, 4, and 8 h after feeding using a tube connected to the pH probe to ensure that the sample originated from the same location as where the pH was measured. Nine milliliters of filtrate was preserved by adding 1 mL of 1% sodium azide, and then the samples were frozen. Ruminal VFA were separated by gas chromatography (Varian 3700, Varian Specialties Ltd., Brockville, ON) using a 15-m (.53 mm i.d.) fused silica column (DB-FFAP Column, J and W Scientific, Folsom, CA).

A t-test was used to analyze the difference in chemical composition between the control and enzyme-treated diets. The data on intake, digestibility, chewing behavior, ruminal pH, and VFA were analyzed using a model that included animal, period, enzyme, forage, and enzyme x forage effects. A general linear model was used to conduct the analyses of variance (SAS, 1989). Significance was declared at P < .05 unless otherwise stated.

Results and Discussion

Feed Composition. The enzyme treatment of the grain lowered dietary ADF and NDF concentrations, regardless of forage source (Table 2), indicating that a partial hydrolysis of the fiber resulted from enzyme application. It is not certain whether the fiber content of the enzyme-treated diet was lowered before feeding because the fiber analyses were done after the experiment was finished. Thus, the interval between enzyme treatment and fiber analysis was substantially longer than the interval between enzyme treatment and feed consumption. We hypothesize that the enzyme increased the susceptibility of the diet to the detergents used in fiber analyses. It is unlikely that the fibrolytic enzymes hydrolyzed the fiber in the barley grain during storage because they were stored in a dry state, which should have precluded enzyme activity (A. Chesson, Rowett Research Institute, personal communication).

Feed Intake. The orts consisted of a higher proportion of forage than did the diet, which indicated a preferential selection of grain over forage. This was
especially evident for the straw diets; straw made up 18.7% of the orts, compared with 5% of the diet (DM basis). Orts from silage diets consisted of 11.2% forage, which indicated that less selection took place for silage diets than for straw diets. The change in concentrate-to-forage ratio between diet and orts for the straw diets was probably caused by a combination of lower palatability and larger particle size of straw compared with silage. Palatability is probably not a limiting factor for high-quality forages, such as silage, but it can limit the intake of poor-quality feeds like cereal straw. Alternatively, the coarser chop length of straw compared with silage may have facilitated ingredient sorting. Chopping the straw finer may have reduced selectivity; however, the beneficial effects of longer particle size on chewing activity and saliva secretion may also have been reduced.

The difference between the ADF concentrations of feed and orts was used to determine the concentrate-to-forage ratio because manual determination of the ratio was very labor-intensive. When the same method was used to determine the concentrate-to-forage ratio of the diets offered, the ratio was 90.4:9.6 for straw diets and 92.5:7.5 for silage diets. This method tended to overestimate the forage component, but, in general, there was agreement between the two methods.

The ADF and NDF concentrations of diets before enzyme treatment (i.e., values for the untreated diets) were used to calculate fiber intake (Table 3). It was not possible to use the fiber values for enzyme-treated diets because enzymes lowered fiber concentrations of the diets. Thus, the effects of enzymes on diet digestibility are based on the assumption that dietary fiber concentrations were similar for steers fed control and treated diets.

Replacing silage with straw in diets fed to growing cattle may lower feed intake (Table 3). Even though there was no significant effect of diet on DMI, intake of straw diets was numerically lower than for silage diets. It may be feasible for commercial feedlot operations to combine straw and silage, rather than to completely replace silage with straw and thus avoid potentially negative effects of straw on feed intake. Reducing the amount of straw in the diet so that it comprises a smaller percentage of the DM may provide the animal with sufficient physical fiber to maintain the positive effect on chewing activity and saliva secretion, while maintaining a high DMI (Beauchemin, 1991).

Intakes of NDF and ADF were lower than expected because of the relatively high proportion of forage in the orts. Even though NDF intakes were somewhat variable among diets, the differences were not significant. However, ADF intake was affected by forage source, as expected. Replacing silage with straw increased ADF intake by 34% because of the higher fiber content of straw.

Eating and Ruminating Activities. The diurnal pattern of eating activity was typical of cattle fed once daily (Figure 1). Eating activity was greatest shortly after feeding, and most activity was observed within the next 12 h. There was a tendency (P = .11) toward increased time spent eating for animals fed enzyme-treated diets (Table 4). However, eating time was not affected by source of forage, even when expressed per kilogram of DM. Mikhail'tsov and Stepanova (1984) found that time spent eating depended on the type, physical structure, and palatability of the feed and that straw was consumed more slowly than other forages. In our study, forage constituted only 5% of dietary DM, and this amount of forage was apparently not sufficient to affect eating behavior.

Enzyme treatment had no effect on the number of meals, but steers fed straw diets tended to eat more meals than steers fed silage diets (11 vs 9.5; P = .06). Number of meals per day and duration of meals were similar to the values of 10/d and 20 min, respectively, reported by Chase et al. (1976). The definition of a meal used in that study was the same as was used in this study, but the steers were fed a TMR that consisted of approximately 70% concentrate and 30% chopped hay. There was no effect of steer on any of the eating characteristics examined.

Enzyme treatment of the concentrate had no effect on rumination time or characteristics of rumination periods. In contrast, steers fed straw diets ruminated approximately one hour per day more than steers fed silage. The effect of forage was also significant when time spent ruminating was expressed per kilogram of DM. The longer rumination time of steers fed straw
diets did not substantially change the pattern of rumination throughout the day (Figure 1). For steers on both diets, only 37.3% ± 1.1 of daily rumination time occurred with the 1st 12 h after feeding.

Because the time spent ruminating per kilogram of ADF was similar for both sources of forage, the longer ruminating time for cattle fed straw diets was due to higher fiber intake. Coarse fiber intake is positively correlated to rumination time (Welch, 1982; Beauchemin, 1991). The longer rumination time of cattle fed straw resulted in more-frequent rumination periods rather than longer periods.

Total time spent chewing averaged between 7.1 and 8.2 h/d, and the time spent ruminating accounted for 55 to 70% of this time. Steers in our study ruminated considerably more than the 2.8 h reported for cattle on a diet of 70% grain and 30% silage or long hay (DM basis) (Sudweeks et al., 1975). Less ruminating time reported in their study was likely due to the use of a diet containing ground corn, citrus pulp, and soybean meal that contained less NDF and had a smaller particle size than the rolled barley grain diets used in our study. The rumination times reported in our study are consistent with the results reported by Hironaka et al. (1992) for growing cattle fed an all-concentrate diet that consisted of steam-rolled barley differing in thickness. In their study, steers ruminated 4.9 or 5.9 h/d when fed medium- or coarse-rolled barley, respectively. However, it is possible that the method used in our study to calculate total time spent eating and ruminating overestimated the times slightly because the cattle did not necessarily eat or ruminate during the entire 5-min period.

Ruminal Characteristics. There were no effects of diet on any of the ruminal pH variables measured (Table 5). Hours during which ruminal pH was either > 6.2 or < 5.8 were calculated because in vitro studies have shown that digestion of OM and fiber are greatly depressed as pH decreases below 5.8 and digestion increases markedly when pH is 6.2 or higher (Shriver et al., 1986). An effect of forage on these ruminal pH variables was expected because cattle fed straw ruminated 1 h/d longer than cattle fed silage. Rumination causes an increase in salivary secretion, and saliva is the most important source of alkali entering the rumen (Kay, 1966).

Mean ruminal pH was higher than values reported by others. Fulton et al. (1979a) reported a mean ruminal pH of 5.5 and 5.6 for wheat and corn diets, respectively, for cattle with ad libitum access to diets containing 35 to 90% concentrates. In another study, steers had ad libitum access to a 90% wheat diet, and mean ruminal pH was 5.4 (Fulton et al., 1979b). Rumsey et al. (1970) fed steers an all-concentrate diet containing mostly corn and found that ruminal pH was affected by level of intake; mean ruminal pH was 5.7 when intake was high, whereas mean ruminal pH was 6.2 when intake was low. Zinn et al. (1994) reported a mean ruminal pH of 5.7 for steers fed a diet of 90% steam-rolled corn. These values are all lower than the mean pH of 6.16 found in our study. However, continuous measurements of ruminal pH were not made in those studies; rather, spot samples were taken 4 to 12 h after feeding when ruminal pH was decreasing (Rumsey et al., 1970; Okamoto, 1976). Mean pH in our study at 12 h after feeding was 5.95.

There was no effect of diet on the diurnal fluctuation of ruminal pH (Figure 2). The slightly different profile observed for B-SI, compared with the other diets, was caused mainly by one steer with a pH profile that remained very low for about 20 h after feeding (Figure 3). In most cases, ruminal pH dropped shortly after feeding and reached an average low of 5.8 to 5.9 approximately 9 to 16 h after feeding. On average, ruminal pH was ≤ 6.2 about 44% of the day, and < 5.8 about 19% of the day (Table 5). These results suggest that fiber digestion was partially inhibited for a substantial period each day. The pH subsequently increased and reached the prefeeding level of about 6.5 approximately 20 h after feeding (Figure 3). This period of rising ruminal pH cor-
Table 4. Number of meals and time spent eating and ruminating during a 24-h period

<table>
<thead>
<tr>
<th>Activity</th>
<th>Diet</th>
<th>Significance</th>
<th>Enzyme</th>
<th>Forage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B-SI</td>
<td>B+SI</td>
<td>B-ST</td>
<td>B+ST</td>
</tr>
<tr>
<td>Eating min/d</td>
<td>155</td>
<td>194</td>
<td>138</td>
<td>164</td>
</tr>
<tr>
<td></td>
<td>295</td>
<td>234</td>
<td>321</td>
<td>328</td>
</tr>
<tr>
<td>Eating min/kg of DM</td>
<td>11.9</td>
<td>15.9</td>
<td>11.4</td>
<td>13.2</td>
</tr>
<tr>
<td></td>
<td>20.2</td>
<td>16.2</td>
<td>25.2</td>
<td>25.1</td>
</tr>
<tr>
<td>Rumination min/d</td>
<td>18.0</td>
<td>21.9</td>
<td>19.7</td>
<td>21.0</td>
</tr>
<tr>
<td></td>
<td>14.0</td>
<td>12.0</td>
<td>15.5</td>
<td>15.5</td>
</tr>
<tr>
<td>Rumination min/kg of DM</td>
<td>6.7</td>
<td>4.9</td>
<td>4.5</td>
<td>5.5</td>
</tr>
<tr>
<td>Number of meals</td>
<td>9.5</td>
<td>9.5</td>
<td>11.3</td>
<td>10.8</td>
</tr>
<tr>
<td>Meal duration, min</td>
<td>18.0</td>
<td>21.9</td>
<td>19.7</td>
<td>21.0</td>
</tr>
</tbody>
</table>

Table 5. Effects of enzyme and forage on characteristics of ruminal fermentation

<table>
<thead>
<tr>
<th>Item</th>
<th>Diet</th>
<th>Significance</th>
<th>Enzyme</th>
<th>Forage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B-SI</td>
<td>B+SI</td>
<td>B-ST</td>
<td>B+ST</td>
</tr>
<tr>
<td>pH mean</td>
<td>6.16</td>
<td>6.18</td>
<td>6.16</td>
<td>6.14</td>
</tr>
<tr>
<td>pH &gt; 6.2, h/d</td>
<td>13.9</td>
<td>14.6</td>
<td>12.8</td>
<td>12.8</td>
</tr>
<tr>
<td>pH &lt; 5.8, h/d</td>
<td>4.5</td>
<td>4.7</td>
<td>5.3</td>
<td>4.1</td>
</tr>
<tr>
<td>Lowest pH</td>
<td>5.71</td>
<td>5.75</td>
<td>5.59</td>
<td>5.63</td>
</tr>
<tr>
<td>Total VFA, mM&lt;</td>
<td>111.9</td>
<td>100.7</td>
<td>104.8</td>
<td>108.8</td>
</tr>
</tbody>
</table>

Nine of the 16 records (four animals in four periods) responded to the period characterized by high rumination and minimal eating activity (Figure 1), which may have increased saliva secretion and buffering capacity within the rumen.

There was considerable discrepancy between the average minimum pH observed for diets when calculated at the same time (5.8 to 5.9; Figure 2) and mean lowest pH (5.59 to 5.75; Table 5). This difference indicates that the lowest pH that was recorded for individual animals did not occur simultaneously for steers fed a particular diet (Figure 3). Even though mean pH remained relatively high for cattle fed high-grain diets, diurnal fluctuations caused the ruminal pH of some animals to drop very low.

Replacing silage with straw increased the molar proportion of acetate (P < .01) and tended (P = .10) to decrease the molar proportion of butyrate (Table 5). The increase in acetate proportion when silage was replaced with straw was probably due to higher ruminal fiber digestibility of straw diets. Enzyme treatment of concentrate had no effects (P > .05) on total VFA or molar proportions of VFA. However, enzyme treatment numerically increased the percent-

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*aB-SI, untreated concentrate and barley silage; B+SI, enzyme-treated concentrate and barley silage; B-ST, untreated concentrate and barley straw; and B+ST, enzyme-treated concentrate and barley straw.

*bNS: interactions between forage and enzyme were not significant (P > .10).

†P < .10.

*P < .05.
tage of propionate \((P = .24)\), tended to decrease the ratio of acetate to propionate \((P = .10)\), and tended to decrease the ratio of acetate plus butyrate to propionate \((P = .14)\). These changes in VFA proportions indicate a potential increase in ruminal starch digestion.

**Digestion.** There was no effect \((P > .05)\) of forage source on digestion of DM, OM, or NDF, but ADF digestion was higher for straw diets than for silage diets \((38.1 \text{ vs } 22.1\%; P < .01; \text{ Table 6})\). Even though barley silage is potentially highly digestible, the ADF digestion of silage diets was extremely low probably because ruminal pH was low for extended periods each day. These results may seem surprising in the light of the preference for silage over straw in feedlot diets. Presumably, this preference is due to the higher potential digestibility of silage combined with the increased ease of handling and storing silage. However, these results indicate that the relative feeding value of high-quality forage is overestimated in high-grain diets.

Higher ADF digestion of straw diets compared with that of silage diets indicates an increase in ruminal fibrolytic activity that was not observed for NDF digestion possibly because of the analytical difficulty that is associated with measuring the NDF content of grain. The higher ADF digestion of straw diets compared with silage diets is consistent with the higher ruminal acetate proportion observed for straw diets. Silage is potentially more digestible than straw, so increased ADF digestion of diets that contain straw indicates improved rumen function. Higher rumination time observed for cattle on straw diets supports this hypothesis, although a concurrent increase in ruminal pH was not observed. A higher ruminal pH was expected for the straw diets than for the silage diets because greater rumination time, higher acetate proportions, and higher ADF digestion were observed for the straw diets. Inconsistent results indicate that mean ruminal pH is not a reliable indicator of potential ruminal fiber digestion. Rumination time may be a better indicator of rumen function and fiber digestion for feedlot cattle that are fed high-grain diets.

Even though digestion of DM and NDF was not improved by enzyme treatment of grain, ADF digestion substantially increased \((P < .05; \text{ Table 6})\). In diets that contain silage, enzymes increased ADF digestion by 55%, and, in diets containing straw, the increase was 14%. A positive effect of enzyme treatment on fiber digestion was expected. Recent studies reported on increased average daily gain in growing cattle that were fed barley diets supplemented with barley silage when a similar enzyme mixture was used (Beauchemin et al., 1997; Iwaasa et al., 1997). In a recent study using ruminally and duodenally cannulated dairy cows fed diets consisting of 45% concentrate, the same enzyme mixture was found to increase total tract digestibility of NDF by up to 12% (W. Z. Yang, unpublished data).
Table 6. Digestion of DM, NDF, and ADF

<table>
<thead>
<tr>
<th>Item</th>
<th>B-SI</th>
<th>B+SI</th>
<th>B-ST</th>
<th>B+ST</th>
<th>SE</th>
<th>Enzyme</th>
<th>Forage</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM</td>
<td>74.8</td>
<td>74.2</td>
<td>72.2</td>
<td>74.4</td>
<td>1.1</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>OM</td>
<td>76.8</td>
<td>75.5</td>
<td>73.8</td>
<td>75.5</td>
<td>1.1</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>NDF</td>
<td>37.4</td>
<td>37.6</td>
<td>40.2</td>
<td>41.9</td>
<td>3.4</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>ADF</td>
<td>17.3</td>
<td>26.9</td>
<td>35.5</td>
<td>40.6</td>
<td>3.1</td>
<td>*</td>
<td>**</td>
</tr>
<tr>
<td>Starch</td>
<td>94.3</td>
<td>91.2</td>
<td>92.2</td>
<td>91.4</td>
<td>1.3</td>
<td>NS</td>
<td>NS</td>
</tr>
</tbody>
</table>

*Digestion calculated using NDF or ADF values for concentrates before enzyme treatment.
*B-SI, untreated concentrate and barley silage; B+SI, enzyme-treated concentrate and barley silage; B-ST, untreated concentrate and barley straw; and B+ST, enzyme-treated concentrate and barley straw.

NS: interactions between forage and enzyme were not significant (P > .10).

*P < .05.

**P < .01.

Even though the interaction between enzyme and forage was not significant, the data indicate that the improvement in fiber digestion due to enzymes may be greater in diets containing small amounts of effective fiber.

The higher ADF digestion that results from the use of enzymes was observed for the silage and the straw diets, which indicated that enzymes may have improved the digestibility of barley hulls. This is consistent with the trend observed for increased molar proportion of propionate. Hulls normally limit the access of ruminal microbes to the inner, highly digestible endosperm (Mcalister et al., 1990). We did not measure ruminal starch digestion in this study, but total tract digestibility of starch was similar for all diets and averaged 92.3%. This value was less than the range of 97 to 99%, in feedlot cattle, reported by others (summarized by Zinn, 1993). This difference is entirely due to the methodology for fecal starch analysis (Rode et al., 1996).

In summary, applying a fibrolytic enzyme mixture to tempered, rolled barley increased total tract ADF digestion by 14% in diets containing barley and straw and by 55% in diets containing barley and silage. Increasing the digestion of fiber may have increased ruminal digestion of grain because the hulls normally limit access of ruminal microbes to the inner, highly digestible endosperm. Enzyme supplements may provide a useful means of improving ruminal digestion of high-concentrate diets, but the most efficacious conditions for their application and the mode of action have yet to be defined.

Feedlot finishing diets in western North America are based primarily on barley grain with a small amount of silage included to maintain adequate rumen function. Increasing the portion of straw in diets fed to feedlot cattle may provide an economically feasible strategy for minimizing digestive disturbances and maximizing gain of growing cattle.

**Implications**

The use of feed enzymes for ruminants has been viewed with considerable skepticism. However, this research indicates that enzymes containing fibrolytic activities may improve nutrient digestion by feedlot cattle on high-concentrate diets that contain barley grain. The most efficacious conditions for the application of feed enzymes in cattle diets have yet to be defined. Additional work is necessary to determine the mode of action so that enzyme mixtures can be formulated and used consistently in barley diets. Feedlot finishing diets in western North America are based primarily on barley grain with a small amount of silage included to maintain adequate rumen function. Incorporating a small portion of straw in diets fed to feedlot cattle may provide an economically feasible strategy for minimizing digestive disturbances and maximizing gain of growing cattle.

**Literature Cited**


