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Effects of four cereal grains on intake and ruminal digestion of harvested forage by beef steers*

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ABSTRACT

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Effects of grain supplements on intake and digestion of roughage diets have been studied extensively, but studies comparing these effects among different grains are limited. Our experiment compared the effects of four cereal grains on roughage intake and ruminal digestion. Five separately penned ruminally cannulated beef steers (average body weight (BW) 194 kg) were used in a 5×5 Latin square design; treatments included prairie hay, or prairie hay plus supplemental barley, corn, sorghum or wheat. Each grain was dry rolled and fed to provide 0.25% BW as starch to a basal diet of prairie hay (in vitro organic matter digestibility, 56 g 100 g^{-1}; crude protein, 10.8 g 100 g^{-1} of organic matter). Urea was added to grains to ensure that supplements were isonitrogenous. Grain supplementation did not affect ($P>0.10$) hay organic matter intake, although digestible organic matter intake was increased ($P<0.10$) by supplementation. Ruminal pH was not affected ($P>0.10$) by grain supplementation. Ruminal ammonia-nitrogen was increased ($P<0.10$) by grain supplements containing urea (barley, corn, and sorghum). Ruminal fluid volume and dilution rate was not affected ($P>0.10$) by grain supplementation, nor were particulate passage rate, ruminal or intestinal retention time, or gastrointestinal dry matter fill. Total tract mean retention time was decreased ($P<0.10$) by barley, corn and wheat supplementation, but unaffected ($P>0.10$) by sorghum. A treatment×sampling time interaction ($P<0.05$) was detected for proportions of ruminal acetate and propionate. Acetate was decreased ($P<0.01$) by barley and increased ($P<0.01$) by sorghum, 4 h after supplementation. At 8 h after supplementation, wheat decreased ($P<0.10$) acetate proportions, while sorghum increased acetate proportions ($P<0.01$). Propionate proportions were not affected ($P>0.10$) by treatments. Wheat supplementation increased ($P<0.01$) ruminal butyrate at 2 and 12 h after supplementation, but sorghum decreased butyrate proportions at 2, 8 and 12 h after supplementation. Barley increased ($P<0.10$) total volatile fatty acid (VFA) concentrations at 4 h after supplementation, but VFA concentrations were not affected by other grains. Grain supplementation increased ($P<0.10$) in sacco

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organic matter disappearance of prairie hay at 48 h of incubation. We conclude that grain supplementation, to provide 0.25% of BW as starch, did not affect hay intake adversely, and slightly increased in sacco digestion of hay organic matter. More readily fermentable grains (barley and wheat) affected ruminal VFA proportions and concentrations.

INTRODUCTION

Grains vary widely in pericarp and seed coat morphology, nature and amount of protein matrix, relative weights of pericarp, germ and endosperm fractions and size, shape and properties of starch granules (Hoseney, 1986). These differences affect bacterial species and rate of bacterial attachment in ruminants consuming grains; as a result, the rate of ruminal starch digestion varies among grains (McAllister et al., 1989). The site and extent of starch digestion are also affected by these properties (Waldo, 1973).

Providing grain supplements to ruminants consuming forage-based diets shifts ruminal microbial populations and feeding preferences that may elicit either positive or negative effects on forage digestion (Yokoyama and Johnson, 1988). The effects of barley and corn fed at high levels (1% of body weight (BW)) on ruminal forage digestion have been examined, and differences have been detected (Brake et al., 1989). Nonetheless, direct comparisons among the major feed grains used in North America have not been evaluated. Our study was designed to compare the effects of four different grains, fed at low levels with respect to BW, on forage intake, ruminal particulate and fluid digesta kinetics, and forage in sacco digestibility. Depending on management goals, limited grain supplementation of forage diets at levels that increase metabolizable energy intake while either reducing, increasing, or not affecting forage intake may be desired. Knowledge of how different grains affect forage intake and digestion, in conjunction with economic considerations, should help beef cattle producers in choosing supplemental grains to meet management goals.

MATERIALS AND METHODS

Five ruminally cannulated crossbred (Hereford×Angus) steers with an average BW of 194 kg were used in a 5×5 Latin square design. Grain supplements used were barley, corn, sorghum, and wheat; all grains were dry rolled. One steer in each collection period received no grain (CON). Each grain was fed to provide 0.25% of BW as starch. Varying amounts of urea were included to insure that grain supplements were isonitrogenous. The basal diet was prairie hay, which consisted primarily of blue grama (*Bouteloua gracilis*), western wheatgrass (*Agropyron smithii*), sideoats grama (*Bouteloua curtipendula*), and silver bluestem (*Andropogon saccharoides*). Minor components of the hay were western ragweed (*Ambrosia psilostachya*), kochia (*Kochia*

scoparia) and threadleaf snakeweed (*Gutierrezia microcephala*). The chemical composition of the hay and grains is shown in Table 1.

Each of the five collection periods was 21 days long. On Day 1, each steer was weighed, and the amount of grain supplement to be fed was calculated based on BW. A period of 14 days was allowed for ruminal adaptation to each supplement. Steers receiving grain were supplemented daily at 07:00 h. Because preliminary observations indicated that the rate of supplement intake varied widely among individual steers, supplements were provided via the ruminal cannula throughout each period. Hay was weighed and fed at 07:00 and 19:00 h; orts were removed and weighed just before feeding. Steers were housed in separate pens measuring 3 m × 10 m, one-third of which was shaded and enclosed on three sides. Mineral blocks (Morton Trace Mineral Block, Morton Salt Division of Morton Thiokol, Chicago, IL; composition of the blocks was 95–98% NaCl, 0.35% Zn, 0.28% Mn, 0.18% Fe, 0.035% Cu, 0.007% I and 0.007% Co) and water were available at all times.

On Day 15 of each period at 05:00 h, steers were dosed with 200 ml of Co-EDTA (Uden et al., 1980) as a fluid-phase marker. Ruminal fluid was obtained from within the mat of the dorsal sac at −2, 0, 1, 2, 4, 6, 8, 12, 24 and 36 h relative to supplementation for determination of pH, volatile fatty acids (VFA) and ammonia-nitrogen (NH_3) concentrations. Ruminal contents were strained through four layers of cheesecloth, after which pH was measured using a combination electrode. Samples were acidified using 1 ml of 7.2 N sulfuric acid per 100 ml of strained ruminal fluid and frozen at −20°C.

Nylon bags were placed in the rumen at 07:00 h on Day 17. Duplicate

TABLE 1

Chemical composition and in vitro organic matter disappearance (IVOMD) of hay and grain supplements

	Hay	Barley	Corn	Sorghum	Wheat
Organic matter (g per 100 g DM)	82.7	86.7	84.8	86.3	87.1
Starch (g 100 g^{-1} OM)	4.7	60.9	67.0	73.7	60.4
Total N (g 100 g^{-1} OM)	1.72	2.11	1.41	1.68	2.54
Crude protein[1] (g 100 g^{-1} OM)	10.8	13.2	8.8	10.5	15.9
NDF (g 100 g^{-1} OM)	76.5	20.0	13.1	10.8	13.1
ADF (g 100 g^{-1} OM)	47.5				
ADL (g 100 g^{-1} OM)	5.3				
ADIN (g 100 g^{-1} OM)	0.2				
Available N[2]	1.5				
IVOMD (g 100 g^{-1})	56	94	88	82	94

[1]Total Kjeldahl N × 6.25.
[2]Total Kjeldahl N-ADIN.
NDF, neutral detergent fiber; ADF, acid detergent fiber; ADL, acid detergent lignin; ADIN, acid detergent insoluble N.

nylon bags containing 3 g of prairie hay ground to pass a 2 mm screen and a blank were removed from the rumen to achieve incubation times of 0, 2, 4, 8, 12, 16, 24, 36, 48, 72 and 96 h. Nylon bags were 7 cm × 16 cm in size, with an average pore size of 27 μm × 47 μm. After removal from the rumen, bags were frozen until all bags had been removed, then thawed and rinsed in tap water until water passing through the bags was clear.

Ytterbium was used as a marker to estimate ruminal particulate kinetics. Hay for Yb labeling was obtained by feeding prairie hay to two ruminally evacuated steers. Masticate was then removed from the rumen, dried at 45°C for 48 h, and immersed in a solution containing 2.5 mg $YbCl_3$ l^{-1} of distilled H_2O for 24 h (McCollum and Galyean, 1985). Masticate was then rinsed thoroughly, air dried at 45°C for 48 h, and dried at 50°C for 24 h. Steers were dosed ruminally with 200 g (dry matter (DM) basis) of water-saturated labeled masticate via the ruminal cannula on Day 17 at 07:00 h. Fecal grab samples were collected at 0, 4, 8, 16, 24, 28, 32, 36, 42, 48, 54, 60, 72, 84, 96, 108, and 120 h after dosing and frozen at −20°C.

Dry matter, ash, and N contents of prairie hay and grain supplements were determined by standard procedures (Association of Official Analytical Chemists, 1984). In vitro organic matter disappearance (IVOMD) of forage and grain supplements (ground in a Wiley mill to pass a 2 mm screen) were estimated each period by techniques described by Tilley and Terry (1963) using inoculum from each steer within a treatment on Day 21 of each period. The starch content of the grains and prairie hay was analyzed according to procedures described by MacRae and Armstrong (1968). Neutral detergent fiber (NDF), acid detergent fiber (ADF), acid detergent insoluble N (ADIN), and acid detergent lignin (ADL) contents of the hay were determined according to non-sequential procedures described by Goering and Van Soest (1970). The NDF of the grains was determined using modifications of the NDF procedure (Van Soest, 1990) for samples containing resistant starch. The particle size distribution of each grain was determined with 20.3 cm sieves (Fisherbrand, Fisher Scientific, Pittsburgh, PA) by placing a 300 g aliquot on the top sieve and agitating for 15 min with an elliptical gyratory motion in a horizontal plane at a rate of 60 gyrations min^{-1}; the distance between the vertices was approximately 30 cm (see Table 2).

Ruminal samples were thawed at room temperature and a 50 ml aliquot centrifuged at 10 000 × g for 12 min. Supernatant fluid obtained 0, 1, 2, 4, 6, 8, 12, 24 and 36 h after dosing was analyzed for Co concentration by atomic absorption spectrophotometry with an air-plus-acetylene flame (McCollum and Galyean, 1985). Fluid passage rates were calculated by regressing the natural logarithm of Co concentration on time after dosing. Ruminal fluid volume was estimated by dividing marker dose by ruminal marker concentration extrapolated to time of dosing (0 h). Volatile fatty acid (VFA) concentrations were measured by gas chromatography using 2-ethyl butyric acid as

TABLE 2

Percentage of grain supplements retained on different sieves

Sieve opening size	Barley	Corn	Sorghum	Wheat
4.75 mm	8.5	11.7	1.5	20.3
2.36 mm	41.2	61.1	79.4	66.2
1.18 mm	44.6	18.2	16.7	10.8
0.6 μm	4.3	7.5	1.9	2.3
0.3 μm	1.6	1.3	0.9	0.7
0.15 μm	0.3	0.3	0.3	0.2
Pan	0.1	0.1	0.2	0.1

an internal standard (Goetsch and Galyean, 1983). Ruminal NH_3 was assayed colorimetrically using a phenol-hypochlorite procedure (Broderick and Kang, 1980).

Nylon bag contents were analyzed for DM and ash (Association of Official Analytical Chemists, 1984). The rate of organic matter (OM) disappearance from nylon bags was calculated using the model described by Ørskov and McDonald (1979).

Fecal grab samples were dried at 50°C for 96 h and ground to pass a 2 mm screen. Ytterbium was extracted from fecal samples using EDTA (Hart and Polan, 1984), and analyzed for Yb concentration by atomic absorption spectrophotometry (nitrous oxide plus acetylene flame). Fecal Yb concentration data were fitted to a one-compartment model (Krysl et al., 1988) to estimate particulate digesta kinetics.

Particulate and fluid passage rates, hay intake, and in sacco disappearance rates were analyzed as a replicated 5×5 Latin square using GLM procedures of the Statistical Analysis Systems Institute (SAS, 1985) with the model including effects for steer within square, period within square, treatment, square and residual. Ruminal pH, NH_3, VFA, and in sacco OM disappearance were analyzed by analysis of variance for a Latin square using a split plot with treatment in the main plot and sampling time in the subplot. Means were separated by predicted difference (SAS, 1985) when treatment×time interactions ($P<0.05$) were not detected. Where significant ($P<0.05$) treatment×time interactions existed, data were analyzed within sampling time.

RESULTS AND DISCUSSION

Analysis of the prairie hay (Table 1) indicated that it was of moderate quality with adequate amounts of available N (Van Soest, 1982). The IVOMD values of wheat and barley were greater than those for corn and sorghum. Wheat and barley starch granules are smaller, with less covalent bonding among starch molecules, and are not as tightly bound to the protein matrix as are corn and sorghum starch granules (Hoseney, 1986); these differences pre-

sumably account for the greater ruminal rate and extent of digestion of wheat and barley. Sorghum contains a greater proportion of peripheral endosperm than corn. Peripheral endosperm is dense, and resistant to water penetration and digestion. In addition, the protein matrix of sorghum has more cross-linked karafins than corn, which reduces the starch digestibility (Rooney and Pflugfelder, 1986) of sorghum.

Although IVOMD values of grains (Table 1) are in general agreement with ruminal digestibility values reported by Theurer (1986), they may vary from actual ruminal digestion. Grains were ground to pass a 2 mm screen before IVOMD analysis, whereas supplement grains were fed dry rolled and had larger particle sizes (Table 2). Increased surface area and the highly buffered in vitro environment might result in greater OM disappearance than would occur in vivo. Galyean et al. (1979, 1981) reported that in sacco disappearance of corn increased with decreasing particle size.

Hay OM intake was not affected ($P>0.10$) by grain supplementation (Table 3). Digestible OM intake (based on IVOMD) of hay also was unaffected ($P>0.10$) by treatment. Addition of grain to the diet increased ($P<0.001$) total digestible OM intake compared with that of CON steers. Differences in total digestible OM intake were related to the amount of digestible OM supplemented as grain. Total digestible OM intake was greater ($P<0.10$) for barley and wheat treatments and least for the sorghum diet, with corn being intermediate and not different ($P>0.10$) from the other grains. A substitution effect of grain was not apparent, rather an increase in digestible energy intake occurred as a result of supplementation with no effect on forage intake. Horn and McCollum (1987) reviewed effects of grain supplementation on forage intake and concluded that concentrates may be fed up to 30 g DM kg^{-1} $BW^{0.75}$ without affecting forage intake. Grain supplementation was below this level

TABLE 3

Organic matter (OM) intake of hay, and digestible OM intake of hay and hay plus supplement (g OM kg^{-1} BW)

Item	Control	Barley	Corn	Sorghum	Wheat	SE[1]
Hay intake	14.3	14.1	14.4	14.0	13.8	0.7
Supplement OM intake	0.0	4.0	3.7	3.3	4.0	
Digestible OM hay intake[2]	8.0	7.9	8.0	7.8	7.7	0.4
Digestible OM hay+ grain intake[3]	8.0[a]	12.3[b]	11.9[bc]	11.0[c]	12.1[b]	0.4

[1]Standard error of least squares means ($n=5$).
[2]Estimated from in vitro OM digestibility of hay.
[3]Estimated from in vitro OM digestibility of hay and grain supplement.
[a,b,c]Row means with different superscripts differ ($P<0.10$).

in our study. For example, wheat was supplemented at 17.3 g kg^{-1} $BW^{0.75}$ on a DM basis.

Ruminal pH was not affected ($P>0.10$) by grain supplementation. Main effect means were 6.6, 6.3, 6.5, 6.4, and 6.4 for CON, barley, corn, sorghum, and wheat, respectively (data not shown). Although a treatment×sampling time interaction was not detected ($P>0.10$), treatment means for pH by hour are listed in Table 4. At −2 h, supplementation with barley and wheat tended ($P=0.18$) to depress pH compared with CON, but this trend was not observed at other sampling times. Negative associative effects have been reported when barley was supplemented to straw diets and pH fell below 6.2 (Mould et al., 1983). Russell and Dombrowski (1980) found that ruminal cellulolytic bacteria in continuous culture were decreased or washed out at pH values ranging from 5.7 to 6.15.

A treatment×sampling time interaction was detected ($P<0.001$) for ruminal NH_3 concentrations; therefore, data are presented by sampling time in Table 5. At 1 h after supplementation, ruminal NH_3 concentrations were increased ($P<0.10$) for steers receiving barley, corn and sorghum. Ruminal NH_3 was greatest for corn, intermediate for sorghum and least for barley, CON and wheat ($P<0.10$). This pattern was similar at 2 h after supplementation ($P<0.05$) and diminished with time until 12 h when ruminal ammonia-N concentrations were not different ($P>0.10$) among treatments. Corn, sorghum and barley contained less N than wheat; therefore, urea was added so supplements would be isonitrogenous. Corn, with the least N content, required the most added urea, followed by sorghum and barley. Ruminal NH_3 concentrations tended ($P=0.12$) to be less for wheat at 8 h and sorghum ($P=0.11$) at 12 h compared with CON. During these times, ruminal NH_3 concentrations were less than the values other researchers have reported as optimal (5.0 mg per 100 ml; Satter and Slyter, 1974) for microbial growth.

TABLE 4

Ruminal pH in relation to time of supplementation of beef steers fed prairie hay and supplemented with grain

Hours after supplementation	Control	Barley	Corn	Sorghum	Wheat	SE[1]
−2	6.6	6.4	6.5	6.5	6.5	0.06
0	6.5	6.5	6.5	6.4	6.6	0.11
1	6.6	6.6	6.7	6.5	6.4	0.11
2	6.6	6.5	6.7	6.6	6.5	0.11
4	6.6	6.3	6.5	6.5	6.3	0.11
6	6.5	6.1	6.4	6.3	6.2	0.14
8	6.5	6.2	6.2	6.3	6.3	0.11
12	6.5	6.2	6.3	6.3	6.3	0.1

[1]Standard error of least squares means ($n=5$).

TABLE 5

Ruminal ammonia-nitrogen concentration (mg per 100 ml) in relation to time of supplementation of beef steers fed prairie hay and supplemented with grain

Hours after supplementation	Control	Barley	Corn	Sorghum	Wheat	SE[1]
−2	5.5	7.0	7.1	7.0	7.5	1.05
0	6.1	6.1	6.8	6.0	7.0	0.89
1	6.2[a]	19.4[a]	58.3[b]	37.6[c]	8.2[a]	7.13
2	6.2[e]	32.1[f]	44.0[g]	27.7[f]	8.9[e]	3.21
4	6.3[e]	18.9[f]	21.7[f]	18.6[f]	5.8[e]	2.65
6	4.9[ab]	8.6[cd]	10.5[c]	6.5[a]	2.6[b]	1.11
8	4.4[a]	4.3[a]	6.8[b]	3.4[a]	2.2[a]	0.92
12	4.8	5.0	4.3	3.1	3.4	0.67

[1]Standard error of least squares means ($n=5$).
[a,b,c,d]Row means with different superscripts differ ($P<0.10$).
[e,f,g]Row means with different superscripts differ ($P<0.05$).

TABLE 6

Ruminal fluid and particulate dynamics in steers fed prairie hay and supplemented with grain

	Control	Barley	Corn	Sorghum	Wheat	SE[1]
Dilution rate (% h^{-1})	9.0	9.6	9.5	10.4	9.5	0.64
Volume (l)	22.9	25.9	24.8	25.3	31.0	3.10
Volume (l kg^{-1} BW)	0.11	0.13	0.12	0.11	0.14	0.01
Particulate passage rate (% h^{-1})	2.4	2.7	2.7	2.5	2.9	0.15
Ruminal particulate retention time (h)	50.1	44.7	45.8	47.6	42.1	2.20
Intestinal particulate retention time (h)	18.4	15.2	16.1	15.6	14.5	1.06
Total mean particulate retention time (h)	68.5[a]	60.0[bc]	61.9[bc]	63.3[ab]	56.6[c]	2.23
DM fill (g kg^{-1} BW)	21.4	21.2	21.7	21.2	18.6	0.83

[1]Standard error of least squares means ($n=5$).
[a,b,c]Row means with different superscripts differ ($P<0.10$).

Ruminal fluid dilution rate and volume were not affected by grain supplementation ($P>0.10$; Table 6). Studies by Henning et al. (1980), Branine and Galyean (1985) and Krysl et al. (1989) reported no effect of grain supplementation on fluid passage rates, while Pordomingo et al. (1991) noted a tendency for increased fluid dilution rates in grazing steers supplemented with whole corn at 0.2% of BW. Krysl et al. (1989) found that steam-flaked sorghum grain increased ruminal fluid volume, but other studies have not found any effects of grain supplementation on fluid volume (Branine and

Galyean, 1985; Freeman, 1987; Pordomingo et al., 1991). Changes in fluid dilution rate with grain supplementation might alter ruminal microbial populations and site of digestion. At present, however, effects of limited amounts of grain supplementation (up to and including 0.4% of BW) on ruminal fluid dynamics appear minimal.

Particulate passage rate and ruminal DM fill were not affected ($P>0.10$) by grain supplements (Table 6); however, ruminal retention time tended ($P=0.18$) to be decreased with wheat supplementation compared with CON. In addition, there was a tendency ($P=0.16$) for both wheat and barley to decrease intestinal retention time. These tendencies resulted in decreased ($P<0.10$) total tract mean retention times with barley, corn and wheat supplementation compared with CON. Wheat supplementation caused the greatest ($P<0.10$) decrease in total tract mean retention time. The retention time with barley or corn did not differ ($P>0.10$) from wheat, but retention time with wheat was less ($P<0.10$) than for sorghum. These data suggest that the differences in passage rates, although not statistically significant, were related to supplementation. Feed intake in forage-fed ruminants is most likely controlled by ruminal fill and passage rates when forage OM digestibility is less than 65% (Ellis, 1978). Steers receiving grain supplements also had greater total feed intake; therefore, to accommodate greater feed intake, an increase in either ruminal fill or passage rate was expected. Except in the case of wheat, gastrointestinal DM fill in supplemented steers did not greatly differ from those on the CON diet. However, numerical differences in particulate passage rates reflect differences in total tract mean retention time and amount of OM consumed. These data agree with those of Pordomingo et al. (1991) for corn and reports by Krysl et al. (1989) for sorghum.

Treatment × sampling time interactions ($P<0.05$) were detected for molar proportions of acetate and propionate. Hence, for clarity of presentation, all VFA data are presented by sampling time. Molar proportion of acetate (Table 7) tended ($P=0.07$ for overall model) to be increased ($P<0.10$) by sorghum supplementation compared with CON, barley, corn, and wheat at 24 h after supplementation (0 h). At 2 h after supplementation, the acetate proportion tended ($P=0.06$ for overall model) to be less ($P<0.10$) for wheat and was greater ($P<0.10$) for sorghum compared with CON. Acetate proportions for barley and corn did not differ from either CON or wheat. Barley decreased ($P<0.10$) acetate proportions at 4 h relative to CON, but sorghum increased ($P<0.10$) acetate proportions compared with CON. Corn did not differ from either CON or wheat. At 8 h after supplementation, the same trends ($P=0.07$ for overall model) as at 2 h after supplementation were observed ($P<0.05$). Decreased ($P<0.10$) acetate with wheat and elevated acetate ($P<0.10$) with sorghum were observed at 12 h after supplementation. Acetate proportions with barley did not differ ($P>0.10$) from CON, while corn did not differ ($P>0.10$) from either CON or wheat.

Ruminal proportionate proportions were not affected ($P>0.10$) by grain supplementation (Table 7). Butyrate proportions were increased ($P<0.10$; Table 7) by wheat and decreased ($P<0.10$) by sorghum at 2 h after supplementation, while barley did not differ ($P>0.10$) from either CON, wheat or corn. Further, corn did not differ ($P>0.10$) from CON or barley. At 8 h after supplementation, sorghum decreased ($P<0.01$) ruminal butyrate proportions compared with the other treatments. The same pattern was evident ($P<0.10$) at 12 h. Grain treatments did not affect ($P>0.10$) ruminal butyrate proportions at 0 and 4 h.

Grain supplementation did not alter ($P>0.01$) ruminal isobutyrate or isovalerate proportions (data not shown). Barley increased ($P<0.10$) valerate proportions at 4 h after supplementation compared with CON, corn and sorghum (Table 8). Sorghum decreased ($P>0.10$) valerate proportions compared with the other grains. At 8 h after supplementation, both barley and wheat increased ($P<0.10$) valerate compared with other treatments, while sorghum decreased ($P<0.01$) valerate compared with other grains. Ruminal valerate was not affected ($P>0.10$) by grain type at other sampling times.

Total VFA concentrations (Table 8) were increased ($P<0.10$) by barley

TABLE 7

Ruminal proportions (mol. %) of major volatile fatty acids in relation to time of supplementation of beef steers fed prairie hay and supplemented with grain

Hours after supplementation	Control	Barley	Corn	Sorghum	Wheat	SE[1]
Acetate						
0	71.5	71.3	70.6	73.2	70.7	0.60
2	71.0	69.4	70.0	73.1	68.4	0.70
4	70.6[a]	68.8[b]	69.9[ab]	73.0[c]	69.0[ab]	0.68
8	70.3	69.5	69.4	72.9	67.8	0.80
12	70.8[a]	70.4[a]	69.2[ac]	72.9[b]	67.6[c]	0.76
Propionate						
0	15.2	15.1	15.9	15.4	15.2	0.46
2	15.4	15.8	15.8	15.3	16.5	0.44
4	15.6	16.2	16.0	15.3	16.7	0.43
8	15.9	16.1	16.4	15.1	17.7	0.69
12	15.5	15.7	16.8	15.2	17.5	0.60
Butyrate						
0	11.2	11.1	10.0	9.1	11.0	0.55
2	11.1[a]	12.1[ac]	11.2[a]	9.3[b]	12.2[c]	0.42
4	11.5	12.3	10.7	9.6	11.9	0.49
8	12.1[a]	12.1[a]	11.9[a]	9.6[b]	12.2[a]	0.29
12	12.2[a]	12.1[a]	12.0[a]	9.9[b]	12.9[c]	0.28

[1]Standard error of least square means ($n=5$).

[a,b,c]Row means with different superscripts differ ($P<0.10$).

TABLE 8

Ruminal proportions of valerate (mol. %) and total ruminal volatile fatty acid (VFA) concentration (mM) in relation to time of supplementation of beef steers fed prairie hay and supplemented with grain

Hours after supplementation	Control	Barley	Corn	Sorghum	Wheat	SE[1]
Valerate						
0	0.67	0.82	0.82	0.57	0.81	0.08
2	0.76	0.99	1.02	0.55	1.00	0.12
4	0.71[acd]	1.15[b]	0.88[d]	0.54[c]	1.06[bd]	0.10
8	0.51[ac]	0.98[b]	0.73[a]	0.34[c]	1.03[b]	0.10
12	0.53	0.75	0.62	0.46	0.82	0.10
Total VFA						
0	82.2	94.4	96.8	86.4	88.3	8.3
2	91.4	103.5	92.9	84.8	80.4	8.0
4	90.0[a]	103.9[b]	85.0[a]	81.2[a]	74.5[a]	6.9
8	82.0	84.6	88.0	83.2	84.0	9.9
12	82.3	83.7	78.1	86.7	84.8	7.1

[1]Standard error of least squares means ($n=5$).
[a,b,c,d]Row means with different superscripts differ ($P<0.10$).

at 4 h after supplementation compared with other treatments. Total VFA concentrations were not affected ($P>0.10$) by grain supplementation at other times. Because wheat and barley are more readily fermentable than the other grains studied, wheat also would be expected to result in a greater total VFA concentration; this expected result may have been diminished by ruminal NH_3 concentration because urea was not supplemented with wheat. Additionally, numerical differences in acetate:propionate ratios and acetate:butyrate ratios suggest that more carbon was incorporated into longer-chain VFA with wheat, which may affect total VFA production. It also is apparent that sorghum generally increased acetate proportions, largely at the expense of butyrate. This is contrary to reports of Krysl et al. (1989), in which sorghum supplementation of steers grazing native rangelands increased butyrate and decreased acetate proportions. Differences may be explained by differences in grain digestibility because Krysl et al. (1989) fed steam-flaked sorghum, which has a greater digestibility than dry-rolled sorghum (Garcia et al., 1981, as cited by Theurer, 1986). Corn supplementation did not affect VFA ratios or concentrations, compared with CON. Volatile fatty acid concentrations were affected, however, when whole corn was supplemented to steers grazing blue grama rangeland (Pordomingo et al., 1991); it is unclear why this response was not observed in our study.

In sacco OM disappearance of hay is presented in Table 9. Initially, barley decreased ($P<0.10$) OM disappearance compared with CON and corn. This decrease may have resulted from the relatively smaller particle size of barley

TABLE 9

Extent of in sacco organic disappearance (mg g^{-1} OM) in beef steers fed prairie hay and supplemented grain

Incubation time (h)	Treatment					
	Control	Barley	Corn	Sorghum	Wheat	SE[1]
2	135[bc]	121[a]	141[b]	123[ab]	131[ab]	4.9
4	134	137	144	138	138	5.5
8	149	169	174	171	167	7.1
12	191	205	220	212	208	9.2
16	235	233	265	245	226	12.7
24	306	331	347	323	301	18.5
36	378	404	447	392	388	24.8
48	411[a]	492[b]	495[b]	467[b]	456[b]	17
72	522	559	581	583	520	26.4
96	602	619	649	637	579	21.8

[1]Standard error of least squares means ($n=5$).
[a,b,c]Row means with different superscripts differ ($P<0.10$).

(Table 2), which might encourage bacteria (i.e. *Bacteriodes succinogenes*) and protozoans (i.e. *Diplodinium* spp.) to preferentially degrade starch rather than cellulose (Yokoyama and Johnson, 1988). More importantly, all grains studied increased ($P<0.10$) OM disappearance of hay relative to CON when incubated in the rumen for 48 h. This positive associative effect corresponds with the particulate mean ruminal retention time data, and indicates potential increased utilization of the hay with low-level grain supplementation. Similar results were described by Pordomingo et al. (1991) when corn was fed at 0.2% of BW to steers grazing warm-season grassland. Forage type and maturity are probable factors determining the presence or absence of associative effects with limited grain supplementation. Sheep studies reported by Meissner et al. (1991) demonstrated that limited grain supplementation (0.3 or 0.6% of BW) reduced in sacco dry matter and NDF disappearance of alfalfa and kikiyu grass, while small positive effects of grain supplementation were described for dry matter and NDF disappearance of Smuts finger, panicum, and eragrostis grasses. Alfalfa and kikuyu grass had greater IVOMD and less NDF content than the other species examined. They concluded that negative associative effects are unlikely when limited grain supplementation is provided to sheep consuming forages having a NDF content greater than 55–60 g per 100 g DM, while digestion of forages containing less NDF may be negatively impacted. Our study offers support to their conclusion because forage used in our study was greater than 55–60 g NDF per 100 g DM (68 g NDF per 100 g DM) and in sacco OM disappearance was somewhat improved by limited grain supplementation.

The rate of in sacco OM disappearance was not affected ($P>0.10$) by treatment (1.4% h^{-1}, 1.8% h^{-1}, 1.9% h^{-1}, 1.7% h^{-1}, and 1.7% h^{-1} for CON, barley, corn, sorghum and wheat, respectively; standard error of least squares means 0.17, $n=5$). Numerically, it appears that grain supplementation increased the rate of OM disappearance at levels fed in our study; however, the effects of barley, corn, and sorghum in our study are confounded with addition of urea. Urea was added to account for differences in N content of grains, so effects of starch digestion on hay intake and utilization could be identified. Because the influence of grains containing urea on ruminal NH_3 concentrations was greatly different from that of supplements not containing urea (wheat), it is possible that the urea exerted an additional effect on ruminal digestion of hay.

CONCLUSIONS

From the results of our study, it appears that grains of varying starch content and structure can be supplemented, when fed at 0.25% of BW (starch basis) to cattle, without negatively affecting intake of harvested forages. In addition to increasing energy intake, in sacco forage OM disappearance may be enhanced by low-level grain supplementation. Furthermore, favorable decreases in the acetate:propionate ratio may be obtained when wheat is supplemented. Because grains are commonly fed to grazing beef cattle without urea, future studies making comparisons among grains without urea addition would be useful.

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