Effects of Sorghum Hybrid and Grain Supplementation of Silage-Based Diets on Nutrient Digestibilities and Passage Rates and Ruminal Metabolism in Growing Steers

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ABSTRACT: Six medium-framed steers, fitted with ruminal cannulas, were utilized in a 6 × 6 Latin square design with a 3 × 2 arrangement of treatments to determine the effects of sorghum hybrid and grain supplementation on nutrient digestibilities and passage rates and ruminal metabolism of silage-based diets fed to growing steers. The diets consisted of three whole-plant silages (a high grain-containing, grain sorghum and middle-season, moderate grain-containing and late-season, low grain-containing forage sorghums), each fed with or without 25% rolled grain sorghum. No significant interactions occurred between sorghum hybrid and grain supplementation for the digestion or passage rate criteria measured.

Ruminal butyrate concentration was the only fermentation characteristic affected by a hybrid × grain supplementation interaction. The grain sorghum silage diets had the highest DM, OM, and ADF digestibilities; the late-season silage diets, the lowest. Digestibility of NDF tended to be highest ($p < 0.10$) for the grain sorghum silage, whereas starch digestibility was not affected by sorghum hybrid. Ruminal ammonia, acetate, propionate, butyrate, and total VFA concentrations were highest for the grain sorghum silage diets. Grain supplementation increased DM and OM digestibilities, but had no effect on digestibilities of NDF, ADF, and starch. Ruminal pH was decreased, but total VFA concentration and acetate : propionate ratio were not affected by grain supplementation.

(**Key Words**: Silage, Grain, Sorghum, Hybrid, Digestibility)

INTRODUCTION

Approximately 3.4 million metric tonnes of sorghum [*Sorghum bicolor*(L) Moench] silage was produced in the United States in 1995 (USDA, 1995). The phenotype and genotype traits of forage sorghum cultivars vary greatly. The wide ranges of plant height, season length, DM content, and whole-plant DM and grain yields contribute to large differences in nutritional value observed among forage sorghum hybrids and varieties (Browning and Lusk, 1966; Nordquist and Rumery, 1967; Kirch et al., 1987; Dalke et al., 1993).

White (1989) reported that DM digestibility of sorghum silage-based diets was correlated negatively to both season length and plant height of the hybrids. Schmid et al. (1976) indicated that grain content of sorghum silage was correlated positively to DM digestibility and live weight gains and correlated negatively to ADF content of the silage. Kirch et al. (1988) reported that the addition of 25% grain (DM basis) to sorghum silage-based diets improved beef cattle performance, particularly for late-season, low grain-containing and middle-season, moderate grain-containing forage sorghum hybrids. Hart (1987) observed that 15 and 30% grain supplementation (DM basis) of sorghum silage-based diets increased intake of digestible DM and nutrient digestibilities compared to unsupplemented silage-based diets. There is no published research on the effects of forage sorghum hybrid and grain supplementation on diet passage rates and ruminal metabolism in cattle fed silage-based diets. These data could help to explain differences in both growth rate and efficiency of feed conversion observed among growing beef cattle fed sorghum silage-based diets (Young, 1995).

The objective of the present experiment was to determine the effects of three phenotypically divergent

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sorghum hybrids and grain supplementation on nutrient digestibilities, passage rates, and ruminal metabolism of silage-based diets fed to growing steers.

MATERIALS AND METHODS

Experimental design and silages

Six medium-framed steers, fitted with ruminal cannulas and averaging 310 kg, were utilized in a 6 × 6 Latin square design with a 3 × 2 factorial arrangement of treatments, which consisted of three whole-plant silages (DeKalb 42Y grain sorghum and DeKalb FS-5 and FS-25E forage sorghums), each fed with or without 25% rolled grain sorghum. DeKalb FS-5 is a middle-season, moderate grain-containing hybrid, and DeKalb FS-25E is a late-season, low grain-containing hybrid. The three sorghum hybrids were produced on a Smolan silty clay loam soil near the Kansas State University campus in Manhattan during the 1992 growing season. Each hybrid was harvested at the late-dough stage of kernel maturity and ensiled in vertical, 3m × 10m concrete stave silos. The steers were housed in a climate controlled metabolism barn in 1.2m × 1.8m individual tie stalls with unrestricted access to water. On day 1 of each period, the steers were allocated randomly to one of the six dietary treatments. The diets (table 1) were formulated to be isonitrogenous and were fed *ad libitum* twice daily for the duration of the experiment. Each Latin square period was 16 days and included an 8-day diet adaptation phase, a 4-day total faecal collection phase, and a 4-day ruminal collection phase.

Table 1. Compositions of the diets

Ingredient	Sorghum silage and level of grain addition					
	Grain sorghum		Middle-season forage sorghum		Late-season forage sorghum	
	0	25%	0	25%	0	25%
	(%) on a DM basis					
Silage	89.00	64.00	89.00	64.00	89.00	64.00
Grain sorghum, rolled	5.09	30.66	–	27.09	0.53	27.55
Soybean meal	4.10	3.50	9.40	7.22	8.85	6.74
Urea	0.51	0.51	0.51	0.51	0.51	0.51
Calcium carbonate	0.48	0.48	0.49	0.49	0.49	0.49
Dicalcium phosphate	0.48	0.51	0.26	0.35	0.28	0.37
Sulfur	0.04	0.04	0.04	0.04	0.04	0.04
Salt	0.20	0.20	0.20	0.20	0.20	0.20
Trace mineral premix[a]	0.02	0.02	0.02	0.02	0.02	0.02
Vitamin premix[b]	0.06	0.06	0.06	0.06	0.06	0.06
Monensin premix[c]	0.02	0.02	0.02	0.02	0.02	0.02

[a] Contained 10% Mn, 10% Fe, 10% Zn, 1% Cu, 0.3% I and 1% Co.
[b] Supplied 1100 IU of vitamin A/kg of diet and 14 IU of vitamin E/kg of diet.
[c] Supplied 250 mg/steer/day.

Nutrient digestibilities

Daily faecal material was weighed and mixed thoroughly, and a 5% aliquot was weighed and dried in a forced-air oven at 50℃ for 72 hours. Weights of feed offered and refused were recorded daily. Daily feed and refused feed samples were dried in a forced-air oven at 50℃ for 48 hours. The dried diet, refused feed, and faecal samples were ground through a Wiley mill to pass through a 1-mm screen and composited for each period by mixing equal amounts of daily samples. Diet, refused feed, and faecal samples were analyzed for OM by ashing in a muffle furnace at 600℃ (AOAC, 1990); total nitrogen (N) by the AOAC (1990) method; NDF and ADF by the procedures of Goering and Van Soest (1970); and starch as total-linked glucose polymers as described by MacRae and Armstrong (1968).

Fermentation profiles

Fermentation profiles were determined as described by Kreikemeier et al. (1990). Briefly, on day 12 of each Latin square period, samples of ruminal digesta were collected before the first feeding (0 hour) and at 2, 4, 6, and 10 hours after feeding. The samples consisted of subsamples from the dorsal blind sac, mid-dorsal region, mid-ventral region, and the reticulum. Ruminal fluid was squeezed from the digesta through four layers of cheesecloth. Ruminal pH was determined immediately on the filtrate, and portions were combined with 25% metaphosphoric acid (wt/vol) (4 parts rumen fluid 1 part metaphosphoric acid) for VFA analysis and with 0.1 *N* HCL (1 part ruminal fluid: 1 part HCL) for ammonia analysis (Broderick and Kang, 1980). Samples for determination of VFA and ammonia were centrifuged at 17,000 × g for 20 minutes. The VFA concentrations were determined using a gas chromatograph, which was fitted with a 4-mm id × 2-m column containing 10% SP 1,200/1% H_3PO_4 on 80/100 W AW Chromsorb. The column was maintained at 135℃, with inlet and detector at 200℃ and a carrier (N_2) flow of 80 ml/minute.

Passage rates

Ytterbium-labeled silage and sodium cobalt EDTA were prepared by the procedures of Teeter et al. (1984) and Uden et al. (1980), respectively. On day 2 of each ruminal collection phase, 1.0 kg of Yb-labeled silage and 250 ml of sodium cobalt EDTA were pulse-dosed ruminally before the first feeding (0 hour). Ruminal fluid and particulate samples were collected at 4, 8, 12, and 24 hours after dosing. Ytterbium was extracted by the procedures of Hart and Polon (1984). Ytterbium and Co concentrations were determined by atomic absorption spectroscopy using nitrous oxide-acetylene and air-acetylene flames, respectively. Liquid and particulate dilution rates were determined by regressing the natural logarithm of the Yb and Co concentrations against time after dosing.

Statistical analysis

Data were analyzed using the SAS GLM procedure (SAS, 1985). Fermentation profile data were analyzed as a split-plot in time 6 × 6 Latin square design using a t-test for mean separations. Terms in the fixed effects model included the main effects of period, steer, time, sorghum hybrid, and grain supplementation and their interactions. Sorghum hybrid, grain supplementation, and sorghum hybrid × grain supplementation (whole-plot) effects were tested for significance by using the whole-plot residual sums of squares (sorghum hybrid × grain suppl-ementation × period × steer). Time, time × sorghum hybrid, time × grain supplementation, and time × sorghum hybrid × grain supplementation (subplot) effects were tested for significance by the subplot residual sums of squares.

Dry matter intake, digestibility, and passage rate data were analyzed as a 6 × 6 Latin square using a t-test for mean separations. Terms in the fixed effects model included period, steer, sorghum hybrid, and grain supplementation and their interactions.

RESULTS AND DISCUSSION

The grain and forage sorghum hybrids used in this experiment were selected to represent a wide range of phenotype and genotype traits. The nutrient compositions of the three sorghum silages are presented in table 2. The grain sorghum hybrid was the shortest (134 cm); had the highest grain yield (5.2 metric tonnes of DM/ha); had the highest percent grain in the whole-plant silage DM (44.0%); had the lowest silage DM yield (13.5 metric tonnes/ha); and had the highest contents of DM, CP, and starch in the whole-plant silage.

The late-season forage sorghum hybrid was the tallest (318 cm); had the highest silage DM yield (18.0 metric tonnes/ha); had the lowest percent grain in the whole-plant silage DM (29.3%); and had the lowest contents of DM, CP, and starch in the whole-plant silage. The middle-season forage sorghum hybrid had intermediate contents of DM, CP, and starch in the whole-plant silage DM. The two forage sorghum silage had much higher NDF and ADF contents than the grain sorghum silage.

Table 2. Compositions of the sorghum silages

Item	Grain sorghum	Middle-season forage sorghum	Late-season forage sorghum
Dry matter(%)	34.5	28.9	27.3
	······ (%) on a DM basis ······		
Crude protein	8.8	7.7	7.3
Neutral detergent fibre	47.8	55.5	57.5
Acid detergent fibre	27.9	36.5	39.8
Starch	45.3	39.7	30.5

The effects of sorghum hybrid on DM intake, intake of digestible DM, and nutrient digestibilities and passage rates are presented in table 3. Dry matter intake was highest for steers fed the grain sorghum silage diets, and 20.9 and 44.6% higher than that for steers fed the middle- and late-season forage sorghum silage diets, respectively. Grain sorghum silage diets supported a higher digestible DM intake by 24.3 and 59.4% compared to the middle- and late-season forage sorghum silage diets, respectively. These results are consistent with those of Browning and Lusk (1966), Kirch et al. (1987), and Dalke et al. (1993). Browning and Lusk (1966) observed that lactating dairy cows fed grain sorghum silage-based diets had higher silage DM intake and digestible DM intake than cows fed forage sorghum silage-based diets. Kirch et al. (1987) and Dalke et al. (1993) both reported that steers receiving grain sorghum silage-based diets had significantly higher DM intakes than those receiving forage sorghum silage-based diets.

Dry matter and OM digestibilities were highest for the grain sorghum and middle-season forage sorghum silage diets. Digestibility of ADF for the grain sorghum silage diets differed significantly from that of the middle- and late-season forage sorghum silage diets. Digestibility of NDF followed the same trend, approaching significance and was the highest for the grain sorghum silage diets and lowest for the late-season forage sorghum silage diets. Starch digestibilities were not significantly affected by sorghum hybrid. Liquid passage rates tended to be highest for the middle-season forage sorghum silage diets, whereas particulate passage rates were not affected by sorghum hybrid.

Table 3. Effects of hybrid in sorghum silage-based diets on DM intake, intake of digestible DM, and nutrient digestibilities and passage rates in growing steers[1]

Item	Grain sorghum	Middle-season forage sorghum	Late-season forage sorghum	SE
DM intake (kg/day)	8.1[a]	6.7[b]	5.6[b]	0.20
Intake of digestible DM (kg/day)	5.1[a]	4.1[b]	3.2[b]	0.16
Digestibility (%)				
DM	62.9[a]	60.4[a]	56.1[b]	1.21
OM	64.0[a]	61.8[ab]	58.9[b]	1.27
NDF	54.8	52.3	48.9	1.86
ADF	53.4[a]	42.2[b]	40.7[b]	2.48
Starch	79.4	83.6	81.5	2.23
Particulate passage rate (%/hour)	5.2	4.8	3.5	0.67
Liquid passage rate (%/hour)	8.1	9.6	8.3	0.49

[1] Values are least square means, and SE is pooled standard error of the mean.
[a,b] Means with different superscripts on the same line are significantly different ($p < 0.05$).

These results are consistent with those of White (1989) and Sonon (1991). The latter author measured the digestibility of grain and forage sorghum silages fed to sheep and reported higher digestibilities of DM and ADF for grain sorghum and middle-season forage sorghum silages than for late-season forage sorghum silage. Sonon (1991) found no differences in digestibility of NDF among the three sorghum silages. White (1989) also reported that grain sorghum silage had higher digestibilities of DM, NDF, and ADF than either middle- or late-season forage sorghum silages.

Differences in DM intake and DM digestibility among the three sorghum silages might be partly attributed to differences in their fibre components. Both NDF and ADF contents were lowest for grain sorghum silage and highest for late-season forage sorghum silage. White (1989) observed a negative association between DM intake and both NDF and ADF contents of sorghum silages. Sonon (1991) reported negative correlations between DM digestibility and NDF content ($r = -0.67$) and ADF content ($r = -0.60$) of sorghum silages. Marten et al. (1976) indicated that ADF content in 36 sorghum silages accounted for about 59% of the variation in DM intake and 80% of the variation in DM digestibility.

Ruminal fermentation characteristics in the growing steers fed the three sorghum silage diets are summarized in table 4. Ammonia, acetate, propionate, butyrate, and total VFA concentrations were highest ($p < 0.05$), whereas acetate : propionate ratio and ruminal pH were lowest for steers fed the grain sorghum silage diets (p <

0.05). The middle- and late-season forage sorghum silage diets produced statistically similar ruminal fermentation characteristics.

The increased VFA concentrations observed for steers receiving the grain sorghum silage diets were likely due to their higher DM intake (table 3) and starch content (table 2). Robinson et al. (1986) reported a linear increase in total VFA, acetate, propionate, and butyrate concentrations with increasing DM intake by lactating dairy cows. Kreikemeier et al. (1990) also reported increased total VFA concentrations with increasing DM intake in steers fed high concentrate diets. Chappel and Fontenot (1968) reported increases in total VFA, propionate, and butyrate concentrations with increasing levels of readily available carbohydrates in purified diets fed to sheep.

Table 4. Effects of hybrid in sorghum silage-based diets on ruminal fermentation characteristics in growing steers[1]

Item	Grain sorghum	Middle-season forage sorghum	Late-season forage sorghum	SE
pH	6.6[a]	6.8[b]	6.8[b]	0.02
Ammonia (mM)	5.6[a]	4.3[b]	4.2[b]	0.18
VFA (mol/100 mol)				
Acetate	61.8[a]	56.2[b]	58.3[b]	1.02
Propionate	19.2[a]	16.3[b]	16.1[b]	0.41
Butyrate	9.3[a]	7.4[b]	7.3[b]	0.21
Total VFA (mM)	96.2[a]	84.9[b]	86.8[b]	1.60
Acetate : propionate	3.3[a]	3.6[b]	3.7[b]	0.05

[1] Values are least square means, and SE is pooled standard error of the mean.
[a,b] Means with different superscripts on the same line are significantly different ($p < .0.05$).

The effects of grain supplementation of sorghum silage-based diets on DM intake, intake of digestible DM, and nutrient digestibilities and passage rates in growing steers are presented in table 5. Grain supplementation increased DM intake and intake of digestible DM by 25 and 34%, respectively, compared to the control diets. Digestibilities of DM and OM were increased by 5.1 and 5.2%, respectively, in the grain-supplemented diets compared to the control diets. Digestibility of starch tended to decrease with grain supplementation. Digestibilities of NDF and ADF, particulate passage rate, and liquid passage rate were not affected by grain supplementation of the sorghum silage-based diets.

Table 5. Effects of grain supplementation of sorghum silage-based diets on DM intake, intake of digestible DM, and nutrient digestibilities and passage rates in growing steers[1]

Item	Grain addition		SE	Probability[2]
	0	25%		
DM intake (kg/day)	6.0	7.5	0.16	**
Intake of digestible DM (kg/day)	3.5	4.7	0.13	**
Digestibility (%)				
DM	58.0	61.6	0.99	*
OM	60.0	63.1	1.04	*
NDF	50.6	53.4	1.52	NS
ADF	46.4	44.4	2.02	NS
Starch	84.0	78.9	1.82	NS
Particulate passage rate (%/hour)	4.9	4.1	0.54	NS
Liquid passage rate (%/hour)	8.9	8.5	0.40	NS

[1] Values are least square means, and SE is pooled standard error of the mean.
[2] NS = not different, * $p < 0.05$ and ** $p < 0.001$.

Jacques et al. (1986) observed 24 and 22% increases in DM intake and digestible DM intake, respectively, and 10.7 and 6.3% decreases in ADF and starch digestibilities, respectively, in growing steers fed sorghum silage-based diets supplemented with 34% rolled grain sorghum (DM basis). Hart (1987) reported increased DM and OM digestibilities with grain supplementation of sorghum silage-based diets, noting that NDF digestibility was increased only at the low level of grain supplementaion, whereas ADF and starch digestibilities were not affected by grain supplementation.

The effects of grain supplementation on ruminal fermentation characteristics are presented in table 6. Grain supplementation decreased ruminal pH and tended to increase ammonia concentration compared to the control diets. Volatile fatty acid concentration and acetate: propionate ratio were not affected by grain supplementation. These results are in contrast to those of Jacques et al. (1986), who observed decreased propionate and total VFA concentrations with grain supplementation of sorghum silage-based diets. Hart (1987) reported no change in pH and decreased concentration of propionate with increasing levels of grain supplementation in sorghum silage-based diets.

Table 6. Effects of grain supplementation of sorghum silage-based diets on ruminal fermentation characteristics in growing steers[1]

Item	Grain addition		SE	Probability[2]
	0	25%		
pH	6.8	6.7	0.02	***
Ammonia (mM)	4.9	4.5	0.18	NS
VFA (mol/100 mol)				
Acetate	58.5	59.0	0.83	NS
Propionate	16.9	17.5	0.33	NS
Butyrate	7.9	8.0	0.17	NS
Total VFA (mM)	88.7	89.9	1.31	NS
Acetate : propionate	3.6	3.5	0.04	NS

[1] Values are least square means, and SE is pooled standard error of the mean.
[2] NS = not different and *** $p < 0.001$.

The ruminal mean pH values (table 6) observed for steers receiving grain-supplemented diets should have been sufficiently high to support maximal fibre digestion. Stewart (1977) reported that the addition of barley to rumen contents reduced microbial cellulolytic activity only when the pH was allowed to drop below 6.6. Hiltner and Dehority (1983) noted that both the rate and extent of *in vitro* cellulose digestion were only affected when initial pH of the ruminal fluid was below 6.3. These results are in contrast to those of van der Linden et al. (1984), who reported that increasing supplementation of corn stover-based diets with corn grain progressively reduced the digestibility of cellulose and hemicellulose by sheep but without changes in ruminal pH. Orskov and Fraser (1975) indicated that the rate of fermentation of the concentrate supplement should not be overlooked. They reported a reduction in fibre digestibility of dried grass when a pelleted barley supplement was compared to a whole barley sopplement.

Results from this experiment showed that whole-plant silage from grain sorghum was of higher nutritional value than silage from middle-or late-season forage sorghums.

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