EFFECTS OF DEGREE OF CORN PROCESSING ON SITE AND EXTENT OF DIGESTION BY BEEF STEERS

P. F. Dew[1], M. S. Brown[1], N. A. Cole[2], and C. D. Drager[1]

[1]Division of Agriculture, West Texas A&M University, Canyon and [2]USDA, ARS, Bushland, TX

Summary

Five beef steers were used to evaluate the effect of degree of corn processing on diet digestion. Corn was processed by dry rolling (DRC) or steam flaking to a bulk density of 28 (SF28) or 22 (SF22) pounds/bushel. Ruminal fluid pH was not influenced by increasing the degree of processing; however, duodenal pH responded quadratically (P = 0.03). Ruminal, postruminal, and total tract starch digestibility were greater (P < 0.08; 32, 42, and 8%, respectively) for SF28 and SF22 compared to DRC. Ruminal feed N digestibility was decreased (P < 0.08) for SF28 and SF22 compared to DRC. The influence of processing on total tract P digestion was inconsistent (quadratic, P = 0.09). Total tract ADF digestibility decreased linearly (P = 0.09). Increasing the degree of processing increased the extent of ruminal and total tract organic matter and starch digestion, and decreased the extent of ruminal feed nitrogen digestion.

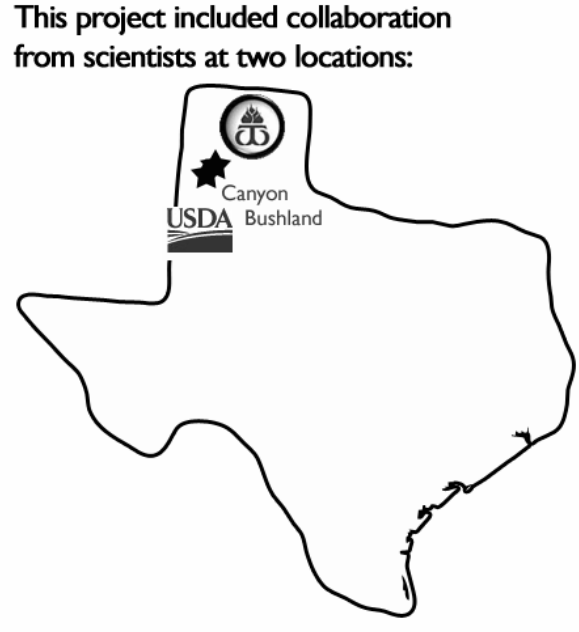
Introduction

Theurer et al. (11) and Swingle et al. (9) reported that ruminal and total tract starch digestion increased linearly with an increasing degree of sorghum processing, whereas Zinn (16) indicated that increasing the degree of corn processing corn did not influence ruminal starch digestion. Increasing the degree of processing has either increased (16) or not influenced (11) microbial N flow from the rumen. Total tract N digestibility has increased linearly (9, 16) or remain unchanged (11) with an increasing degree of grain processing. Steam flaking of both sorghum and corn has been reported to alter P content (8), but information regarding the effect of degree of grain processing on P digestibility is lacking. The objective of this study was to further evaluate the influence of degree of processing on site and extent of digestion.

Experimental Procedures

Five crossbred beef steers were surgically prepared with cannulas in the rumen and proximal duodenum and used in a 5 x 3 Latin rectangle to evaluate the effect of degree of corn processing on site and extent of digestion. All procedures were reviewed and approved by the Amarillo Area Cooperative Research, Education, and Extension Triangle Institutional Animal Care and Use Committee (Protocol number 2000-08).

Steers were housed indoors (70°F) in individual pens (8 ft x 8 ft) with concrete floors and allowed a six-week adjustment period. Dietary treatments consisted of dry-rolled corn (DRC) and steam-flaked corn processed to bulk densities 28 and 22 lb/bu (SF28 and SF22, respectively). Degrees of processing were selected to produce products with 25, 50, and 75% of total starch as enzymatically available in vitro (15 as modified by 4). Diets were prepared approximately every 7 d during the experiment (Table 1), and chromic oxide was added to the diet as



an indigestible flow marker.

Steers were offered quantities of feed sufficient to allow ad libitum access in equal proportions every 2 h using an automated feeding system. Following a diet adjustment period (d 1 to 8), samples of feed offered and orts from d 9 through 14 were composited within steer for later laboratory analyses. Ruminal, duodenal, and fecal samples were collected from all steers at 0800 and 1800 on d 13 and 14.

Samples were lyophilized and ground in a Wiley mill to pass a 1-mm screen. All samples were analyzed for DM (105°C for 24 h) and ash (1), N, P (10), starch, Cr (6), ADF, and NDF (14). Duodenal samples reconstituted with 0.1N HCl (13) were analyzed for ammonia concentration (3). Whole ruminal contents for each steer within period were incubated in a formalin solution (3.7% formaldehyde; w/v) at 4°C for 3 h before homogenizing, straining, and differential centrifugation to isolate ruminal bacteria (2, 13). Bacterial pellets were lyophilized before grinding in a coffee grinder and analyzed for DM, ash, and N as described previously.

Purine concentration of isolated bacterial cells and duodenal digesta samples were determined (12 and 17 as modified by 5). Equations used to calculate nutrient flow and digestibility are presented in the Appendix to this paper.

All data were analyzed using the MIXED procedures of SAS (SAS Institute, Cary, NC). The model included the fixed, repeated effect of period, the fixed effect of treatment, and the random effect of steer. Treatment sums of squares were partitioned into linear and quadratic effects of the degree of processing. Contrast coefficients were generated using the IML procedures of SAS (SAS Institute, Cary, NC) to reflect actual treatment spacing.

Results and Discussion

Ruminal pH was not affected by treatment (P = 0.15), and averaged 5.89, 5.63, and 5.62 ± 0.15 for DRC, SF28, and SF22, respectively. However, duodenal pH responded quadratically (P = 0.03), and was highest for DRC and SF22 and lowest for SF28 (2.58, 2.51, and 2.22 ± 0.17, respectively).

Apparent OM flow to the duodenum (Table 2) responded quadratically with an increasing degree of processing (P = 0.10) ; flow was highest for DRC, intermediate for SF22, and lowest for SF28. True OM flow increased linearly (P = 0.08) as degree of corn processing increased. Microbial OM flow did not differ (P > 0.21). Apparent and true ruminal OM digestibility responded quadratically (P < 0.07); apparent and true ruminal OM digestibility were increased approximately 30 and 18%, respectively, for SF28 and SF22 compared with DRC. Postruminal OM digestibility as a percentage of duodenal entry did not differ, whereas fecal OM excretion decreased

Table 1. Diet ingredient and chemical composition (% of DM)

	Degree of Processing[a]		
Item	DRC	SF28	SF22
Dry-rolled corn	78.00	—	—
Steam-flaked corn, 28 lb/bu	—	78.00	—
Steam-flaked corn, 22 lb/bu	—	—	78.00
Alfalfa hay	10.00	10.00	10.00
Cane molasses	6.00	6.00	6.00
Cottonseed meal (41%)	2.18	2.18	2.18
Calcium carbonate	1.18	1.18	1.18
Urea	1.10	1.10	1.10
Dry-rolled sorghum	0.36	0.36	0.36
Chromic oxide	0.30	0.30	0.30
Salt	0.25	0.25	0.25
Ammonium sulfate	0.25	0.25	0.25
Magnesium oxide	0.18	0.18	0.18
Premix[b]	0.20	0.20	0.20
Chemical composition			
DM	88.57	88.04	88.01
Starch	54.87	57.86	59.54
CP	14.24	13.67	13.75
P	0.32	0.32	0.28
ADF	5.78	5.57	5.88
NDF	13.82	13.20	12.73
Ash	5.08	5.01	4.67
NE_m, Mcal/kg[c]	2.03	2.09	2.09
NE_g, Mcal/kg[c]	1.39	1.43	1.43

[a]DRC = dry-rolled corn, SF28 = 28 lb/bu steam-flaked corn, SF22 = 22 lb/bu steam flaked corn. Bulk density was determined as grain exited the rolls.

[b]Premix contained (DM basis): 0.027% $CoCO_3$, 1.965% $CuSO_4$, 2.289% $FeSO_4$, 0.031% EDDI, 2.582% MnO, 4.225% $ZnSO_4$, 5.0% mineral oil, 4.5%, vitamin. A (30,000 IU/g), 1.62% vitamin E (500 IU/g), 7.875% Rumensin-80, 1.8% Tylan-100, 68.09% cottonseed meal (41%).

[c]Calculated based on tabular values (NRC, 1996) of NE_m and NE_g for dry-rolled and steam-flaked corn (2.18 and 1.50, and 2.33 and 1.62 Mcal/kg, respectively). Remaining chemical composition determined by laboratory analysis.

quadratically (P = 0.08) as degree of processing increased. Total tract OM digestion was increased 12 and 8% for SF28 and SF22, respectively (quadratic, P = 0.01).

Starch flow and digestibility by steers in all segments of the digestive tract were altered by degree of processing (Table 2). The flow of starch to the duodenum (Linear; P = 0.01), and fecal starch excretion (Quadratic; P = 0.07) by steers consuming SF28 and SF22 was approximately 74 and 91 % less than steers fed DRC. Ruminal and total tract starch digestibility responded quadratically (P = 0.08); ruminal and total tract starch digestibility of SF28 and SF22 were increased 34% and 31%, respectively, compared with DRC. Consequently, postruminal starch digestibility (percentage of intake) decreased quadratically with increasing degree of processing (P = 0.04), whereas postruminal digestion of starch as a percentage of duodenal entry increased linearly with an increasing degree of processing (P < 0.01).

Degree of corn processing did not alter flow of total, nonammonia, or microbial N from the rumen (Table 3). The amount of feed N reaching the duodenum increased linearly as the degree of corn processing increased (P = 0.08), and was inversely related to a linear decrease (P = 0.04) in ruminal digestibility of feed N (decreased approximately 25% for SF28 and SF 22 compared with DRC). Microbial efficiency (g of microbial N/kg of OM truly fermented) responded quadratically with an increasing degree of processing (P = 0.07); microbial efficiency was lowest for SF28, intermediate for SF22 and highest for DRC.

Postruminal digestion of N and total tract N digestibility were similar among treatments (P > 0.15). Degree of processing did not influence flow of P to the duodenum, ruminal digestion, or postruminal digestion of P (Table 3). Total tract P digestion responded quadratically (P = 0.09); total tract P digestibility was increased 16% and decreased 17% for SF28 and SF22, respectively, compared with DRC.

Fecal excretion of ADF (168, 172, and 191 $\pm$ 21 g/d) did not differ (P > 0.32), whereas total tract ADF digestibility decreased linearly (P = 0.09; 42.8, 42.8, and 29.9 $\pm$ 4%) as degree of processing increased. Fecal excretion of NDF tended (P = 0.13) to respond quadratically (341, 286, and 359 $\pm$ 34 g/d). Total tract NDF digestion responded quadratically (*P* = 0.07; 53.3, 59.6, and 49.5 $\pm$ 3%) and was increased 12% for SF28 and decreased 7% for SF22 compared to DRC.

Implications

Increased ruminal and total tract organic matter digestibility due to degree of processing was closely related to similar changes in starch digestibility. Decreased ruminal digestion of dietary nitrogen and microbial efficiency may be a function of decreased corn protein degradability from the application of heat during the steam flaking process. Increasing the degree of corn processing decreased dietary fiber digestion, which may be indicative of small decreases in ruminal pH inhibiting cellulolytic bacteria. A consistent pattern of the influence of degree of corn processing on total tract phosphorus digestion was not evident, whereas phosphorus intake accounted for only 35 to 43% of duodenal phosphorus flow.

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Appendix

Dry matter flow was determined by the equation: DM flow (g/d) = Cr consumed (g/d) / Cr concentration (in duodenal chyme or feces; g of Cr/g of DM). Nutrient flow (g/d) was the result of nutrient concentration (in duodenal chyme or feces) x DM flow (g/d). Nutrient digestibility was determined by the equation: Nutrient digestibility, (%) = 100 – 100 x ([% Cr in feed DM/ % Cr in duodenal chyme or fecal DM] x [% nutrient in duodenal chyme or fecal DM/ % nutrient in feed DM]). Microbial N flow to the duodenum was determined by the equation: Microbial N flow (g/d) = duodenal OM flow (g/d) x duodenal purine concentration (g of purine/g of duodenal OM) x bacterial total N:purine (g/g, from individual bacterial isolates). Microbial OM flow to the duodenum was determined by the equation: Microbial OM flow (g/d) = duodenal OM flow (g/d) x duodenal purine concentration (g of purine/g of duodenal OM) x bacterial OM:purine (g/g, from bacterial isolates). True rumen OM flow was calculated as total OM flow less microbial OM flow. Feed N flow was calculated as total N reaching the duodenum less ammonia N and microbial N, and includes any endogenous N.

Table 2. Effect of degree of corn processing on site and extent of organic matter and starch digestion by steers

	Degree of processing[a]				Contrast[c]	
Item	DRC	SF28	SF22	SE[b]	Linear	Quadratic
Dry matter						
Intake, g/d	5314	5734	5432	462	—	—
Excretion, g/d	1227	787	870	103	0.02	0.14
Organic matter						
Intake, g/d	5056	5446	5210	440	—	—
Duodenal flow, g/d						
Apparent	2319	1470	1639	206	0.01	0.10
True	1295	600	689	198	0.08	0.16
Microbial	1031	860	950	79	0.26	0.21
Fecal excretion, g/d	1047	578	694	95	0.01	0.08
Digestibility						
Ruminal (apparent), %	54.0	72.9	68.1	4	0.01	0.01
Ruminal (true), %	74.2	88.6	86.5	4	0.003	0.07
Postruminal, % of entry	54.7	60.7	57.5	3	0.26	0.20
Total tract, %	79.9	89.5	86.6	2	0.002	0.01
Starch						
Intake g/d	3026	3510	3324	268	—	—
Duodenal flow, g/d	877	176	272	159	0.01	0.13
Fecal excretion, g/d	242	17	25	34	0.001	0.11
Digestibility						
Ruminal, %	70.1	93.8	91.7	5	0.003	0.08
Postruminal						
% of intake	21.9	4.5	7.6	4	0.006	0.10
% of entry	61.6	87.7	87.2	7	0.007	0.27
Total tract, %	92.1	99.7	99.3	1	0.001	0.08

[a]DRC = dry-rolled corn, SF28 = 28 lb/bu steam-flaked corn, SF22 = 22 lb/bu steam flaked corn. Bulk density was determined as grain exited the rolls.
[b]Most conservative standard error of the least square means.
[c]Linear and quadratic effects of degree of corn processing.

Table 3. Effect of degree of corn processing on site and extent of digestion of nitrogen and phosphorus by steers

	Degree of processing				Contrast[c]	
Item	DRC	SF28	SF22	SE[b]	Linear	Quadratic
Nitrogen						
Intake g/d	114	117	116	5.4	—	—
Duodenal flow, g/d						
Total N	130.9	137.7	139.4	6.1	0.24	0.87
Non-ammonia N	125.7	134.2	135.4	5.9	0.17	0.75
Ammonia N	5.2	4.0	3.9	0.8	0.15	0.68
Microbial N	84.8	81.4	81.8	6.5	0.70	0.84
Feed N	37.6	53.4	53.5	7.0	0.08	0.60
Microbial efficiency[d]	24.4	18.4	20.5	1.7	0.05	0.07
Fecal excretion, g/d	33.3	30.9	31.9	3.0	0.59	0.58
Digestibility						
Ruminal feed N, %	68.9	51.2	51.7	6.3	0.04	0.39
Postruminal						
% of intake	83.1	97.2	96.2	7.8	0.15	0.49
% of entry	73.0	78.4	77.4	2.4	0.27	0.71
Total tract, %	70.0	72.8	72.4	2.3	0.29	0.52
Phosphorus						
P intake g/d	16.8	16.9	13.4	0.7	—	—
Duodenal flow, g/d						
Total P	39.5	39.6	38.4	4.8	0.90	0.84
Endogenous P[e]	25.1	23.6	21.8	3.7	0.55	0.84
Fecal excretion, g/d	9.7	7.6	8.6	2.0	0.57	0.49
Digestibility						
Ruminal, %	-126.2	-178.3	-158.8	37.7	0.44	0.48
Postruminal						
% of intake	141.4	223.2	189.1	29.6	0.26	0.32
% of entry	78.1	80.7	76.4	4.5	0.91	0.43
Total tract, %	49.6	57.4	41.1	8.2	0.60	0.09

[a]DRC = dry-rolled corn, SF28 = 28 lb/bu steam-flaked corn, SF22 = 22 lb/bu kg/L steam-flaked corn.
[b]Most conservative standard error of the least square means.
[c]Linear and quadratic effects of degree of corn processing.
[d]Microbial N, g/kg of OM truly fermented in the rumen.
[e]Represents total P entering the duodenum less P intake.