Effect of degree of corn processing on urinary nitrogen composition, serum metabolite and insulin profiles, and performance by finishing steers[1,2]

M. S. Brown[3], C. R. Krehbiel[4], G. C. Duff, M. L. Galyean[5], D. M. Hallford, and D. A. Walker

Department of Animal and Range Sciences, New Mexico State University, Las Cruces 88003-0003

ABSTRACT: Two experiments were conducted to determine the effect of degree of corn processing on urinary ammonia and urea N concentrations, serum metabolite and insulin concentrations, and feedlot performance of steers. Corn was processed by either dry rolling to .54 kg/L bulk density (DR42; 42 lb/bushel) or steam flaking to a bulk density of .36 or .26 kg/L (28 [SF28] and 20 [SF20] lb/bushel, respectively). Degrees of processing were selected to generate final products with 25, 50, or 75% enzymatically available starch. Available starch, expressed as a percentage of total starch for DR42, SF28, and SF20, averaged 24.5, 56.4, and 81.1% in Exp. 1 and 22.4, 60.1, and 80.1% in Exp. 2. In Exp. 1, 29 steers were housed in individual outdoor pens and adapted to a 90% concentrate diet over 21 d. Whole blood and urine were collected before feeding and at 4 and 8 h after feeding on d 0, 7, 14, 21, 28, 84, and 140. Daily DMI decreased linearly ($P < .03$) as degree of processing increased, whereas water intake did not differ ($P > .42$) among treatments. Average daily gain, ADG:DMI, and hot carcass weight responded quadratically ($P < .04$) to an increasing degree of processing. Urinary ammonia and urea N concentrations were not influenced ($P > .30$) by degree of processing. Whole blood packed cell volume, serum glucose, creatinine, D(−)-lactate, L(+)-lactate, and lactate dehydrogenase activity did not differ ($P > .15$) among treatments. For insulin data, ME intake on the day of sample collection was evaluated as a covariate. On d 28, serum insulin (2.49, 2.95, and 1.80 ± .33 ng/mL) responded quadratically ($P = .04$) as degree of processing increased. Serum insulin did not differ ($P = .52$) on d 84, whereas insulin (5.77, 7.51, and 4.12 ± .98 ng/mL) responded quadratically ($P = .02$) on d 140. In Exp. 2, 216 steers were blocked by BW into two blocks (18 pens; 12 steers/pen) and assigned to the same treatments used in Exp. 1. Daily DMI and carcass weight responded quadratically ($P < .05$), whereas ADG and ADG:DMI increased linearly ($P < .04$) with increasing degree of processing. Results suggest that the degree of corn processing influences serum insulin concentrations of feedlot steers; however, serum metabolites, urinary nitrogen composition, and carcass characteristics were generally not affected by degree of corn processing.

Key Words: Fattening, Grain, Insulin, Metabolites, Performance, Processing

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Introduction

Limits to small intestinal starch digestion by cattle have been reported (Krehbiel et al., 1996), and Huntington (1997) estimated the threshold to be less than 1.5 kg of starch/d in concentrate-adapted animals. Thus, maximal energetic efficiency of finishing cattle necessitates a high extent of ruminal starch fermentation (Owens et al., 1996), which can be increased through grain processing.

The degree of processing for sorghum that supports optimum animal performance has been variable (Lofgreen and Dunbar, 1970; Xiong et al., 1991; Swingle et al., 1999), whereas limited data are available for corn (Zinn, 1990a). Increasing the degree of processing of steam-flaked grain has linearly decreased ruminal pH and DMI and can increase ruminal propionate concentration (Zinn, 1990a; Reinhardt et al., 1997); however, total ruminal VFA and lactate concentrations have been unchanged (Reinhardt et al., 1997). Although shifts in the site and extent of nutrient digestion occur as degree of processing is increased (Zinn, 1990a; Swingle et al., 1999), duodenal flow of microbial CP has

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[3] Present address: Division of Agric., West Texas A&M Univ., WTAMU Box 60998, Canyon, TX 79016.

[4] Correspondence: Dept. of Anim. Sci., 208b Anim. Sci. Bldg., Oklahoma State Univ., Stillwater, OK 74078 (phone: 405/744-8857; fax: 405/744-7390; E-mail: kclinto@okstate.edu).

[5] Dept. of Animal Sci. and Food Tech., Texas Tech Univ., Lubbock.

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either increased (Zinn, 1990a) or been unchanged (Alio et al., 1996). Portal flux of glucose has not been influenced by an increased degree of processing (Lozano et al., 1995), whereas portal flux of lactate and energy absorption have been increased (Theurer et al., 1990, 1991). Hence, determining the impact of absorbed metabolites on metabolism and performance by beef cattle as influenced by the degree of corn processing warrants investigation. Therefore, our objective was to determine the effect of degree of corn processing on urinary nitrogen composition, serum metabolite and insulin concentrations, and feedlot performance of steers.

Materials and Methods

Animals and Diets. In Exp. 1, 29 crossbred steers were assigned randomly to receive diets based on dry-rolled corn (.54 kg/L or 42 lb/bushel bulk density; **DR42**) or corn steam-flaked to a bulk density of .36 or .26 kg/L (28 [**SF28**] and 20 [**SF20**] lb/bushel, respectively). Degrees of processing were selected to yield final products in which 25, 50, or 75% of total starch was enzymatically available in vitro (Xiong et al., 1990a) to an amyloglucosidase enzyme (No. A7255, Sigma Chemical Co., St. Louis, MO). Steers were housed in individual soil-surfaced, outdoor pens (2.4 × 6.1 m). In Exp. 2, 216 crossbred steers were blocked by BW into two blocks and assigned randomly to 18 pens (12.2 × 27.4 m; 12 steers/pen). Animals were handled and cared for according to a protocol reviewed and approved by the New Mexico State University Institutional Animal Care and Use Committee.

Experiment 1 was conducted from October 1998 to March 1999, and Exp. 2 was conducted from November 1998 to April 1999. Animals in both experiments were gradually adapted to a 90% concentrate diet (Table 1) fed once daily by offering 60, 70, and 80% concentrate diets for 6, 7, and 7 d, respectively. Diets were formulated to contain 13% CP, .5% Ca, .35% P, and .8% K. Diet transitions were made by maintaining constant NE_g intake on the day of transition to the new diet. Although some degree of intake restriction was imposed during the adaptation period, level of DMI by d 28 for steers in Exp. 1 and 2 averaged 2.1 and 2.2% of BW, respectively. Feed refused in Exp. 1 was weighed weekly, and feed was offered in quantities sufficient to allow ad libitum access in both experiments. Steers had ad libitum access to water from tanks equipped with flow meters to record water consumption in Exp. 1. Because one tank serviced adjacent pens, animals within a treatment were stratified by BW, and pairs were assigned randomly to adjacent pens. Water intake was not measured in Exp. 2.

Table 1. Ingredient and chemical composition of 90% concentrate diet DM

	Degree of processing[a]		
Item	DR42	SF28	SF20
Ingredient composition, % of DM			
Dry-rolled corn	76.55	—	—
Steam-flaked corn, .36 kg/L	—	76.56	—
Steam-flaked corn, .26 kg/L	—	—	76.69
Sorghum sudangrass hay	9.81	9.80	9.74
Cane molasses	4.89	4.89	4.86
Yellow grease	2.63	2.63	2.62
Soybean meal (44% CP)	2.35	2.35	2.34
Urea	1.10	1.10	1.10
Limestone	.73	.73	.72
Dicalcium phosphate	.43	.43	.43
Salt	.29	.29	.29
Ammonium sulfate	.24	.24	.24
Premix[b]	.98	.98	.97
Chemical composition, % of DM			
Exp. 1			
Starch	48.6	52.1	54.9
CP	12.7	12.3	12.3
ADF	9.3	9.5	9.3
Ash	4.1	4.1	4.1
ME, Mcal/kg	3.05	3.33	3.34
NE_m, Mcal/kg	2.07	2.30	2.31
NE_g, Mcal/kg	1.41	1.61	1.61
Exp. 2			
Starch	49.7	45.8	51.9
CP	12.7	12.2	12.1
ADF	9.4	9.2	9.5
Ash	4.3	4.2	4.0
ME, Mcal/kg	3.06	3.18	3.28
NE_m, Mcal/kg	2.08	2.18	2.26
NE_g, Mcal/kg	1.42	1.50	1.57

[a] DR42 = dry-rolled corn, SF28 = .36 kg/L steam-flaked corn, SF20 = .26 kg/L steam-flaked corn. Bulk density was determined as grain exited the rolls.

[b] Premix contained (DM basis): $CoCO_3$, .02%; $CuSO_4$, .183%; CaI_2, .015%; $FeSO_4$, 1.09%; $MnSO_4$, .791%; $ZnSO_4$, .79%; MgO, 1.67%; mineral oil, .221%; vitamin A (30,000 IU/g), .67%; vitamin E (500 IU/g), .27%; Rumensin-80, 1.69% (33 mg monensin/kg of diet); Tylan-40, 1.12% (11 mg tylosin/kg of diet); wheat middlings, 91.47%.

One day before each experiment started, steers were vaccinated for clostridial organisms (BarVac Alpha-7; Boehringer Ingelheim Animal Health, St. Joseph, MO), treated for internal and external parasites (Cydectin; Fort Dodge Animal Health, Fort Dodge, IA), implanted (Synovex-S; Fort Dodge Animal Health), branded, ear-tagged, and weighed. Individual unshrunk BW also was determined on the 1st d of the experiment, and the two consecutive BW measurements were averaged to determine initial BW. Interim unshrunk BW was determined at 28-d intervals. Steers in Exp. 1 and light-block steers in Exp. 2 were reimplanted (Synovex-S) on d 84. Steers in Exp. 1 were slaughtered at a commercial facility after 143 d, whereas steers in Exp. 2 were slaughtered after 112 (heavy block) and 161 d (light block). Hot carcass weight (**HCW**) was determined after slaughter, and carcasses were evaluated by trained personnel after a 24-h chill for the following measurements: s.c. fat depth at the 12th rib; longissimus muscle area; percentage kidney, pelvic, and heart fat; yield grade; marbling score; quality grade (USDA, 1997); and presence of liver abscesses (Brink et al., 1990). Because of mechanical difficulties during transit to the processing plant, one load of steers from the heavy block in Exp. 2 was unloaded and fasted an additional 12 h before slaughter. Primarily three pens of steers were affected, and each treatment was represented equally. Therefore, average dressing percentage (63.4%) was calculated from HCW and final shrunk (4%) BW of Exp. 2 steers that were not influenced by this event, and carcass weight was calculated for the remaining steers (final shrunk BW × .634). In Exp. 1, dressing percentage was calculated from HCW and final shrunk BW.

Grain Processing. Before experiments began, the rolls (Serial No. 5318; 45.7 cm × 61.0 cm; Ferrell Ross, Oklahoma City, OK) were reconditioned, and steam lines inside the steam chest (Model No. 960, Ferrell Ross) were replaced. Width, depth, and height of the steam chest was 1.168, .66, and 3.832 m, respectively. Capacity of the steam chest was approximately 2,250 kg of grain. Steam lines spanned the width of the steam chest and were spaced vertically every 61.0 cm. In Exp. 2, electricity and natural gas consumption during processing were recorded and averaged across days of the experiment. A grain conditioner or tempering agent was not used in either experiment. Retention time of grain in the steam chest was maintained at 75 min to produce SF28 and 115 min to produce SF20. Dry-rolled corn was prepared by adjusting the distance between the rolls so that no whole corn exited the rolls, and bulk density of the final product was approximately .54 kg/L. Diet samples were collected and DM content of the diets and dietary ingredients were determined weekly during both trials. Samples of unprocessed corn were obtained before processing, and samples of processed grain were collected for determination of bulk density every 20 to 30 min during processing. This sampling interval allowed for approximately each 1,000 kg of processed grain to be represented. Grain samples were immediately stored at –20°C after collection. Each time grain was processed (approximately once per week), DM of unprocessed and processed grain was determined to monitor moisture uptake. Diet and grain samples were composited by 28-d periods, allowed to air dry, and ground in a Wiley mill to pass a 1-mm screen.

Laboratory Methods. Grain and diet samples were analyzed for total and available starch (Xiong et al., 1990a), Kjeldahl N, ash (AOAC, 1990), and ADF (Goering and Van Soest, 1970). In Exp. 1, urine and whole blood (via jugular venipuncture) were collected before feeding and at 4 and 8 h after feeding on d 0, 7, 14, 21, 28, 84, and 140. Urine was collected according to the procedure of D. Griffin and L. J. Perino (personal communication). After steers were restrained, debris was removed from the sheath orifice area, and approximately 5 cm of a 15-mL centrifuge tube was inserted into the sheath. The majority of steers (75 to 80%) urinated at this point. For steers that did not urinate, the centrifuge tube was securely fastened using a rubber band to hair extending beyond the end of the sheath so as not to restrict tissue blood flow. Animals were released, temporarily housed in a holding pen for 15 to 30 min, and then restrained again to remove the fastener and urine tube. In Exp. 2, whole blood (jugular venipuncture) was collected from two animals per pen before feeding on d 28, 112, and 161 to assay serum insulin; d 112 and 161 corresponded to the end of the finishing period for heavy and light blocks, respectively. Heparinized whole blood was centrifuged (Adams Micro-hematocrit; Model No. CT2900; Clay-Adams, New York) for 10 min in microhematocrit tubes to determine packed cell volume. Serum was harvested from whole blood that was allowed to clot at ambient temperature for 30 min and centrifuged at 1,000 × g for 20 min. Serum was composited within day in Exp. 1 and stored at –20°C until it was assayed for glucose (No. 315-100; Sigma Chemical Co., St. Louis, MO), lactate dehydrogenase activity (No. 500-C; Sigma), creatinine (No. 555; Sigma), and insulin (Diagnostic Products Corp., Los Angeles, CA). Serum was composited within pen in Exp. 2 and stored at –20°C until it was assayed for insulin. Intraassay and interassay coefficients of variation for insulin were less than 6 and 4%, respectively. Deproteinized serum was analyzed for D(–)-lactate (Gawehn and Bergmeyer, 1974; Brandt et al., 1980) and L(+)-lactate (Gutmann and Wahlefeld, 1974; Engel and Jones, 1978) in Exp. 1. Urine was composited within day, acidified with .10 volume of 7.2 N H_2SO_4, and analyzed for ammonia N (Broderick and Kang, 1980) and urea N (Kit no. 535; Sigma) in Exp. 1.

Data Analyses. All Exp. 1 data and Exp. 2 grain chemical composition data were analyzed as a completely random design (SAS, 1998), whereas regression analysis (PROC REG; SAS, 1998) was used to describe the relationship between available starch and bulk density. Total water intake was calculated as the sum of water contained in feed consumed and water consumed by drinking. Because of the loss of data points (two per period) as a result of water meter malfunction, total water intake was expressed per 100 kg of average BW during a period. Intake of ME was calculated from derived estimates of dietary NE based on animal performance and DMI (NRC, 1996). For Exp. 1 insulin data, ME intake on the day of sample collection was evaluated as a covariate. Initial analysis indicated that the effect of ME intake was significant ($P < .10$) on d 84; however, treatments did not differ ($P = .52$) either with or without inclusion of the covariate. Therefore, the diet adaptation period (d 1 to 28) was analyzed as a split-plot in time (Gill, 1986) without a covariate, and d 84 and 140 were analyzed independently for serum insulin. Repeated measures analysis was used for packed cell volume, urinary ammonia and urea N, and serum metabolite data. Performance and insulin data for Exp. 2 were analyzed as a randomized complete block design (SAS, 1998), and the model included effects for treatment and block. Incidence of liver abscesses and percentage of carcasses grading low Choice or greater were evaluated using chi-square analyses (SAS, 1998) with animal as the experimental unit, whereas pen served as the experimental unit for all other data in Exp. 2. Treatment sums of squares were partitioned in both

Table 2. Chemical composition of processed grain DM

	Degree of processing[a]			
Item	DR42	SF28	SF20	SE[b]
Grain DM, %				
Exp. 1[c]	87.5	80.4	79.7	1.6
Exp. 2[c]	87.1	79.9	80.5	1.2
Total starch, % of DM				
Exp. 1	64.0	66.3	66.5	2.5
Exp. 2	64.2	64.9	65.5	1.5
Available starch, % of total starch				
Exp. 1	24.5	56.4	81.1	2.7
Exp. 2	22.4	60.1	80.1	2.6
Available starch, mg of glucose/g of grain DM				
Exp. 1	173	410	592	19.6
Exp. 2	158	419	568	14.9
Crude protein, % of DM				
Exp. 1[c]	8.83	8.29	8.12	.16
Exp. 2[c]	8.91	8.36	8.36	.15
Ash, % of DM				
Exp. 1[c]	1.40	1.07	.87	.05
Exp. 2[c]	1.36	1.09	.88	.06

[a] DR42 = dry-rolled corn, SF28 = .36 kg/L steam-flaked corn, SF20 = .26 kg/L steam-flaked corn. Bulk density was determined as grain exited the rolls.

[b] Standard error of the least squares mean, n = 5.

[c] Linear effect ($P < .02$).

experiments into linear and quadratic components using coefficients for unequal treatment spacing.

Results and Discussion

Grain Processing. Before the experiments began, samples of steam-flaked corn were obtained to determine the minimum steaming time necessary and the appropriate bulk densities needed to generate products with approximately 50 and 75% enzymatically available starch. For example, steaming times of 40, 60, and 80 min resulted in SF28 with 39.2, 40.7, and 52.6% available starch expressed as a percentage of total starch. It was subsequently determined that the minimum steaming time required was 75 min, and processing SF20 at maximum production rate resulted in a retention time of 115 min. Similar to our experiments, Reinhardt et al. (1997) maintained maximum mill production rate of sorghum and observed an increase in retention time (50, 70, and 90 min) as degree of processing increased (.36, .32, and .28 kg/L). Zinn (1990b) reported a linear increase in starch availability (5.2, 6.4, and 11.2% of total starch) using an assay different from that used in the present experiments for corn steamed for 34, 47, or 67 min and flaked to .35, .35, and .32 kg/L. Because starch availability seems to be increased only after the flaking step (Preston, 1998), it is unclear whether starch availability of corn steamed for 67 min would have increased if it were processed to a bulk density similar to the other two steaming times.

Average available starch content of processed grain (Table 2) was slightly higher for SF28 and SF20 than we had intended, and the interval between treatments was not equal. Therefore, coefficients used for statistical contrasts were adjusted to reflect the measured available starch in both experiments. The relationship between percentage of available starch, glucose release, and bulk density in the present experiments was described by the following equations: 1) available starch, % of total = 132.4 − .2015(g/L bulk density); n = 18, $s_{y/x}$ = 5.69, r^2 = .944 and 2) glucose release, mg/g of grain DM = 968.3 − 1.487(g/L bulk density); n = 18, $s_{y/x}$ = 42.4, r^2 = .943. Enzymatic assays for starch availability determination using amyloglucosidase incubation seem to be the most commonly used; however, conditions used are generally specific to each laboratory. Despite varying assay conditions, increasing the degree of processing of corn or sorghum has resulted in linear increases in starch availability (Zinn, 1990a; Xiong et al., 1991; Theurer et al., 1999) and rate of DM fermentation (Brown et al., 1998).

The reason for the discrepancy between total starch content of processed grain (Table 2) and the lower dietary starch content of DR42 in Exp. 1 and SF28 in Exp. 2 (Table 1) is not evident. Processed grain samples were collected at 20- to 30-min intervals at the time grain was processed (approximately once per week), and diet samples were obtained from the feed bunk. Alterations in DM content or composition might have occurred during bin storage between the time steam-flaked grain was prepared and the time it was included in the diet, despite monitoring DM content of bin-stored processed grain at weekly intervals.

A small number of experiments have used the assay conditions of Xiong et al. (1990a). Brown et al. (1998) reported a starch availability (% of total starch) of 23% for unprocessed corn, whereas starch availability increased linearly (53, 64, and 78%) for corn steamed for 40 min and flaked to .38, .33, and .28 kg/L at the facility described by Xiong et al. (1991). In a series of experiments, Xiong et al. (1990a,b, 1991) processed sorghum grain to various degrees and determined starch availability (mg of glucose/g of grain DM) or glucose release and extent of gelatinization (% of DM) using the same enzymatic assay. However, glucose release values ranging from 559 to 678 mg/g for .28 kg/L steam-flaked sorghum were reported by Xiong et al. (1990a,b, 1991), presumably a result of differences in total starch content between experiments. These limited data seem to suggest that considerable differences can exist in the steaming time needed to increase starch availability between grain processing facilities. Therefore, comparisons of bulk density as the description of degree of processing would be accurate only to the extent that the use of different processing protocols at different facilities influence the chemical and physical modifications of processed grain similarly.

Grain DM decreased linearly ($P < .006$) with an increasing degree of processing (Table 2). Moisture uptake for SF28 averaged 7.1 and 7.2 percentage points, whereas SF20 averaged 7.8 and 6.6 percentage points in Exp. 1 and 2, respectively. Swingle et al. (1999) maintained retention time of steam-flaked sorghum at 40 min and reported grain DM of 88, 82.9, and 83.9% for unprocessed sorghum and sorghum that was steam-flaked to .36 and .26 kg/L, respectively. Zinn (1990a) steamed corn processed to .36 and .26 kg/L for 34 min each. Dry matter of unprocessed corn averaged 88%, whereas .36 kg/L and .26 kg/L steam-flaked corn averaged 84 and 85% DM, respectively. At the same facility (Zinn, 1990b), moisture uptake of 5, 5, and 8 percentage points was observed for corn steamed for 34, 47, and 67 min, respectively. When a tempering agent is not used, the initial 5 percentage points of moisture uptake seem to occur between 12 (Johnson et al., 1968) and 34 min (Zinn, 1990a,b). However, moisture uptake of approximately 8 percentage points seems to occur by increasing the duration of steam exposure from between 47 and 67 min (Zinn, 1990b) to 75 min.

Ash and CP content decreased linearly ($P < .02$) as degree of processing increased (Table 2). Preston (1998) summarized six experiments designed to assess changes in chemical composition of sorghum and corn during multiple steps of the steam-flaking process. Ash, P, and K decreased during the flaking step (14, 23, and 17%, respectively), and ash and CP content decreased as the degree of processing increased. Moreover, P and K were correlated (r = .64 and .81, respectively) with ash content. Defoor et al. (1998) reported a tendency for lambs fed steam-flaked sorghum to have a higher P retention than lambs fed dry-rolled sorghum, perhaps reflecting decreased P content in steam-flaked sorghum. The basis for decreased CP and ash as degree of processing increases is unclear.

Mill production rate, energy consumption, and energy costs of processing grain for Exp. 2 are presented in Table 3. Increasing the degree of processing from DR42 to SF28 and SF20 resulted in a 39 and 24% decrease in production rate, respectively. Likewise, use of natural gas and electricity increased 35 and 19%, respectively, as the degree of processing increased from SF28 to SF20. Similar results for steam-flaked sorghum were reported by Reinhardt et al. (1997).

Feedlot Performance. In Exp. 1, DMI (Table 4) decreased linearly ($P < .03$) with an increasing degree of processing. Overall DMI averaged 1.9, 1.8, and 1.7% of BW (89.2, 83.1, and 77.9 g/kg of $BW^{.75}$) for DR42, SF28, and SF20, respectively. Average total daily water intake (feed and drinking water; 4.88, 4.73, and 4.59 ± .42 L/kg of BW for DR42, SF28, and SF20, respectively, n = 3) was not influenced ($P > .42$) by degree of processing. Steer ADG (Table 4) responded quadratically ($P < .04$) as the degree of processing increased; overall ADG increased 17.7% by replacing DR42 with SF28, and ADG decreased 11.4% by replacing SF28 with SF20. Gain efficiency responded quadratically ($P < .04$) as the degree of processing increased. Overall gain efficiency was increased 19.8% by replacing DR42 with SF28, but gain efficiency decreased 4% with a further increase in the degree of processing. Carcass characteristics (Table 5) generally did not differ ($P > .33$) among treatments; however, HCW responded quadratically ($P < .02$), in a manner similar to the response in ADG (Table 4). Only one steer had evidence of liver abscesses; therefore, liver abscess data were not analyzed statistically.

In Exp. 2, DMI (Table 6) responded quadratically ($P < .05$) as the degree of processing increased. Dry matter intake averaged 2.0, 2.0, and 1.9% of BW (91.9, 91.1, and 86.6 g/kg of $BW^{.75}$). Steer ADG increased linearly ($P < .04$) with degree of processing; overall ADG was increased 8% as SF28 replaced DR42, but ADG decreased 2% as SF20 replaced SF28. Gain efficiency increased linearly ($P < .04$) with degree of processing. Overall ADG:DMI increased 7 and 3% as the degree of processing increased to SF28 and SF20, respectively. Hot carcass weight (Table 7) responded quadratically ($P < .05$), and KPH tended ($P = .08$) to increase linearly as the degree of processing increased. Although the percentage of carcasses grading low Choice or greater differed numerically, carcass prices (US $/45.4 kg) averaged $103.80, $104.40, and $104.07 for steers fed DR42, SF28, and SF20, respectively. Collectively, optimum animal performance was evident when grain was processed to between .36 and .26 kg/L bulk density, which corresponded to starch availability between 410 and 568 mg of glucose/g of grain DM or between 55 and 80% of total starch.

Based on metabolic body size, DMI was 3, 9, and 12% less in Exp. 1 than in Exp. 2 for steers fed DR42, SF28, and SF20, respectively. Level of DMI in Exp. 1 for steers fed SF28 and SF20 was comparable to earlier observations for pen-fed steers (83.4 and 79.5 g/kg of $BW^{.75}$; Zinn 1990a). Steer ADG:DMI responded quadratically in Exp. 1 and increased linearly in Exp. 2, whereas DMI decreased linearly in Exp. 1 and quadratically in Exp. 2. An explanation for the discrepancy in animal performance between the present two experiments is not readily apparent. Generally, the magnitude of increased ADG and ADG:DMI between DR42 and SF28

Table 3. Mill production rate, energy consumption, and cost of processing corn grain (Exp. 2)[a]

	Degree of processing[b]		
Item	DR42	SF28	SF20
Production rate, kg of DM/h	1,844	1,121	848
Natural gas			
Consumption, kL/1,000 kg of DM	—	28.01	37.73
Cost, $/1,000 kg of DM	—	2.40	3.23
Electricity			
Consumption, kL/1,000 kg of DM	5.66	30.61	36.54
Cost, $/1,000 kg of DM	.46	2.48	2.96
Total energy cost, $/1,000 kg of DM	.46	4.88	6.19

[a] Electricity cost = $ 0.0812/kWh, natural gas cost = $ 0.0857/kL.

[b] DR42 = dry-rolled corn, SF28 = .36 kg/L steam-flaked corn, SF20 = .26 kg/L steam-flaked corn. Bulk density was determined as grain exited the rolls.

Table 4. Effect of degree of corn processing on performance of individually fed finishing beef steers (Exp. 1)

	Degree of processing[a]			
Item	DR42	SF28	SF20	SE[b]
Initial BW, kg	327	331	330	4.6
Final BW, kg	529	569	540	10.9
DMI, kg/d[c]	8.22	8.12	7.42	.22
ADG, kg/d[d]	1.41	1.66	1.47	.06
ADG:DMI[d]	.172	.206	.197	.006

[a] DR42 = dry-rolled corn, SF28 = .36 kg/L steam-flaked corn, SF20 = .26 kg/L steam-flaked corn. Bulk density was determined as grain exited the rolls.
[b] Standard error of the least squares mean, n = 9.
[c] Linear effect ($P < .03$).
[d] Quadratic effect ($P < .04$).

and the magnitude of the decrease in DMI between SF28 and SF20 in Exp. 2 was approximately 50% of that in Exp. 1. Steers in Exp. 1 were maintained individually, and pen space was restricted to 14.6 m^2. In Exp. 2, steers were housed in groups of 12/pen (12.2 × 27.4 m) and were allowed an average of 27.8 m^2 of pen space/steer. An increased level of physical activity for pen-fed steers would not seem to explain the decreased magnitude of performance improvement in Exp. 2 compared with Exp. 1; observed dietary NE_m and NE_g for steers fed DR42 was similar in both trials. Diet palatability might have been adversely affected in Exp. 1, because diets were prepared approximately twice per week and contained supplemental fat. Moreover, the lower dietary starch content (Table 1) of DR42 in Exp.1 and SF28 in Exp. 2, relative to the other degrees of processing within each experiment, likely influenced animal performance.

Others feeding 60 to 88% concentrate diets have reported decreased DMI (5 to 9%), decreased DMI:ADG (7 to 14%), increased dietary NE_m (11%) and NE_g (13%) concentration, and similar carcass characteristics or an increase in internal fat content as .31 or .34 kg/L steam-flaked corn replaced dry-rolled corn (Zinn, 1987; Barajas and Zinn, 1998; Zinn et al., 1998). Similar to results for Exp. 2, Ramirez et al. (1985) and Galyean et al. (1992) indicated that DMI and carcass characteristics did not differ, whereas ADG increased (3 to 6%) and DMI:ADG decreased (10%), as .38 kg/L steam-flaked replaced unprocessed corn. In contrast, Zinn (1990a) indicated that increasing the degree of processing (.36, .31, and .26 kg/L) did not influence DMI (7.49, 7.31, and 7.16 ± .51 kg/d), ADG (1.40, 1.39, and 1.32 ± .13 kg/d), DMI:ADG (5.34, 5.26, and 5.49 ± .28), or carcass characteristics. The numerical decrease in DMI between .36 and .26 kg/L corn of Zinn (1990a) was similar to that observed in the present Exp. 2 (4.4 vs 5.3%) between SF28 and SF20, whereas steers in Exp. 1 exhibited a decrease of 8.6%. Zinn (1990a) further reported that ADG and ADG:DMI numerically decreased

Table 5. Effect of degree of corn processing on carcass characteristics of individually fed finishing beef steers (Exp. 1)

	Degree of processing[a]			
Item	DR42	SF28	SF20	SE[b]
Hot carcass wt, kg[c]	330	357	339	7.8
Dressing, %	65.0	65.3	65.4	.7
Marbling score[d]	425	412	465	39
Quality grade[e]	6.12	6.10	6.90	.66
Choice, %	50.0	60.0	70.0	—
12th-rib fat depth, cm	1.20	1.09	1.06	.11
Longissimus muscle area, cm^2	84.8	85.9	85.3	4.2
KPH[f]	2.06	2.00	1.90	.15
Yield grade	2.66	2.70	2.53	.25

[a] DR42 = dry-rolled corn, SF28 = .36 kg/L steam-flaked corn, SF20 = .26 kg/L steam-flaked corn. Bulk density was determined as grain exited the rolls.
[b] Standard error of the least squares mean, n = 9.
[c] Quadratic effect ($P < .02$).
[d] Slight = 300 to 399; Small = 400 to 499.
[e] $Select^+ = 6.00$; $Choice^- = 7.00$.
[f] Kidney, pelvic, and heart fat as a percentage of carcass weight.

Table 6. Effect of degree of corn processing on performance of pen-fed finishing beef steers (Exp. 2)

	Degree of processing[a]			
Item	DR42	SF28	SF20	SE[b]
Initial BW, kg	327	327	327	.5
Final BW, kg	547	559	555	3.6
DMI, kg/d[c]	8.79	8.80	8.33	.12
ADG, kg/d[d]	1.58	1.71	1.67	.03
ADG:DMI[d]	.180	.194	.200	.002

[a] DR42 = dry-rolled corn, SF28 = .36 kg/L steam-flaked corn, SF20 = .26 kg/L steam-flaked corn. Bulk density was determined as grain exited the rolls.

[b] Standard error of the least squares mean; n = 6.

[c] Quadratic effect ($P < .05$).

[d] Linear effect ($P < .04$).

5.7 and 1.6%, respectively, by replacing .36 with .26 kg/L corn. However, ADG decreased 11.4 and 2.3% in Exp. 1 and 2, respectively, whereas ADG:DMI decreased 4.4% in Exp. 1 and increased 3.1% in Exp. 2 as .26 replaced .36 kg/L corn.

Feed intake decreased linearly in Exp. 1 and quadratically in Exp. 2, and CP of processed grain decreased linearly in both experiments as the degree of processing increased. Dietary CP was .4 to .6 percentage points lower in both experiments for SF28 and SF20 than for DR42 (Table 1), raising the question of the potential influence of metabolizable protein (**MP** supply on animal performance. Results of Milton et al. (1997) and Shain et al. (1998) suggest that the degradable intake protein **DIP** supply for finishing cattle gaining 1.50 to 1.65 kg/d and fed diets based on dry-rolled corn with either 10% prairie hay or 5% alfalfa hay plus 5% corn silage is adequate when urea is included at .88 to .9% of DM as the sole source of supplemental N. Based on these observations, urea and soybean meal were included at 1.1 and 2.3% of DM in our experiments in an attempt to provide a nonlimiting level of DIP as the degree of processing increased. According to Level 1 of NRC (1996), the DR42 diet in our experiments provided MP in excess of requirements. Similarly, Zinn (1990a) included urea at 1.16 and .8% of DM and cottonseed meal at 0 and 5% of DM in a finishing and metabolism trial, respectively. In the metabolism trial, Zinn (1990a) reported that microbial efficiency did not differ, whereas increased duodenal flow of microbial N (9%), ruminal feed N digestibility (3%), and postruminal N digestibility (8%) were observed as the degree of processing of steam-flaked corn increased from .26 kg/L to .36 kg/L bulk density. Alio et al. (1996) indicated that ruminal DM digestibility and duodenal flow of microbial CP were numerically increased (10 and 4%, respectively) as .28 kg/L steam-flaked corn replaced .44 kg/L corn. Using the OM and N digestibility coefficients and

Table 7. Effect of degree of corn processing on carcass characteristics of pen-fed finishing beef steers (Exp. 2)

	Degree of processing[a]			
Item	DR42	SF28	SF20	SE[b]
Hot carcass wt, kg[c]	330	340	337	2.0
Marbling score[d]	399	428	414	12
Quality grade[e]	5.94	6.41	6.06	.24
Choice, %	50.0	61.2	47.1	—
12th-rib fat depth, cm	.90	1.01	.94	.06
Longissimus area, cm^2	82.0	81.0	82.8	1.3
KPH[fg]	1.96	2.07	2.08	.05
Yield grade	2.47	2.72	2.56	.10
Liver abscess incidence, %	5.2	1.5	6.0	—

[a] DR42 = dry-rolled corn, SF28 = .36 kg/L steam-flaked corn, SF20 = .26 kg/L steam-flaked corn. Bulk density was determined as grain exited the rolls.

[b] Standard error of the least squares mean, n = 6.

[c] Quadratic effect ($P < .05$).

[d] Slight = 300 to 399; Small = 400 to 499.

[e] Select$^-$ = 5.00; Select$^+$ = 6.00.

[f] Linear trend ($P = .08$).

[g] Kidney, pelvic, and heart fat as a percentage of carcass weight.

microbial efficiency values of Zinn (1990a) and assuming that small intestinal N digestibility is equivalent to postruminal N digestibility, predicted UIP flow, microbial CP flow, and MP supply for cattle fed SF28 and SF20 in Exp. 1 and 2 were 533, 468, and 713 g/d; 474, 470, and 724 g/d; 572, 507, and 768 g/d; and 523, 528, and 806 g/d, respectively. These calculated data imply that an increased extent of ruminal OM and N and small intestinal N digestibility might have offset decreased CP intake as degree of processing increased. The lack of a decrease in predicted MP supply of cattle fed SF20 compared with SF28 in both experiments suggests that the pronounced decrease (Exp. 1) or small numerical decrease (Exp. 2) in ADG was not a function of MP status.

Metabolism. The effects of treatment and time did not interact ($P > .08$) for packed cell volume, urinary ammonia N, urinary urea N, or serum metabolites in Exp. 1. Moreover, packed cell volume (38.8, 38.5, and 39.9 ± .9%), urinary urea N (162, 133, and 150 ± 19 m*M*), urinary ammonia N (24.2, 22.4, and 24.7 ± 4.8 m*M*), serum glucose (96.8, 97.5, and 95.3 ± 3.2 mg/dL), serum creatinine (1.82, 1.95, and 1.98 ± .07 mg/dL), serum D(−)-lactate (.04, .04, and .06 ± .008 m*M*), serum L(+)-lactate (1.50, 1.48, and 1.43 ± .10 m *M*), and lactate dehydrogenase activity (1,008, 1,068, and 1,014 ± 39 U/L) were not influenced ($P > .15$) by degree of corn processing.

Our interest in determining the influence of degree of processing on urinary N composition and serum metabolites stems from earlier observations from glucose-challenged ewes (Brown et al., 1999). Limited data indicate that splanchnic blood flow is similar for steers fed dry-rolled or steam-flaked sorghum (Theurer et al., 1990), whereas net portal lactate absorption increases with degree of processing (16%; Theurer et al., 1991). Present results for serum glucose seem to agree with earlier observations for cattle fed 90% concentrate diets during finishing (Duff et al., 1994; Matsuzaki et al., 1997). McAtee and Trenkle (1971) reported plasma glucose of 90, 105, and 100 mg/dL before offering heifers a 63% dry-rolled corn diet at 1.25% of BW and at 4 and 8 h after feeding. Leedle et al. (1995) observed an average plasma glucose concentration of 104 mg/dL during diet adaptation. Plasma glucose of heifer calves offered ad libitum access to an 80% concentrate diet was unchanged throughout the feeding period (195 d), averaging 101 mg/dL (Yambayamba, et al., 1996). In contrast, Ellenberger et al. (1989) reported that plasma glucose of steers offered ad libitum access to a 70% concentrate diet numerically decreased (from 94 to 79 mg/dL) during the feeding period.

During the adaptation period (d 1 to 28) in Exp. 1, the effects of treatment and time interacted ($P < .05$) for serum insulin (Table 8). On d 7, serum insulin tended to increase linearly ($P = .09$) with an increasing degree of processing. Degree of processing did not influence ($P > .14$) serum insulin on d 14 or 21. On d 28, insulin responded quadratically ($P = .04$) with increasing degree of processing. The ME intake covariate remained in the model ($P = .09$) on d 84; however, degree of processing did not influence ($P = .52$) serum insulin concentrations (3.72, 3.72, and 4.43 ± .77 ng/mL). On d 140, ME intake was removed from the model ($P = .16$). Serum insulin (5.77, 7.51, and 4.12 ± .98 ng/mL) on d 140 responded quadratically ($P = .02$) with an increasing degree of processing. In Exp. 2, serum insulin was not influenced ($P > .40$) by degree of processing on d 28 (2.13, 2.61, and 2.57 ± .83 ng/mL for DR42, SF28, and SF20, respectively) or at the end of the feeding period (6.45, 8.90, and 8.05 ± 1.56 ng/mL).

Table 8. Effect of degree of corn processing on serum insulin concentration (ng/mL) during the adaptation period of individually fed beef steers (Exp. 1)[a]

	Degree of processing[b]			
Day	DR42	SF28	SF20	SE[c]
0	.7	.8	.7	.1
7	1.3	1.8	2.1	.3
14	1.8	2.3	2.4	.4
21	2.4	2.9	2.5	.4
28[d]	2.5	3.0	1.8	.3

[a] Treatment × time ($P < .005$); ME intake covariate ($P > .30$) on each collection day. Within a day, samples were collected before feeding and at 4 and 8 h after feeding.

[b] DR42 = dry-rolled corn, SF28 = .36 kg/L steam-flaked corn, SF20 = .26 kg/L steam-flaked corn. Bulk density was determined as grain exited the rolls.

[c] Standard error of the least squares mean, n = 9.

[d] Quadratic effect ($P = .04$).

Little is known of the effect of degree of processing on serum or plasma insulin concentrations. Murphy et al. (1994) reported that serum glucose and insulin concentrations did not differ between steers fed whole or dry-rolled corn. Gross et al. (1988) indicated that plasma glucose concentration increased (4 mg/dL), whereas net portal insulin flux and arterial plasma insulin concentration at 2-h intervals did not differ between steers fed 90% concentrate diets based on either dry-rolled wheat or dry-rolled sorghum. Although ME intake did not influence serum insulin in Exp. 1, increased serum insulin of steers fed SF28 compared with DR42 might be related to shifts in products of ruminal fermentation. Increased duodenal flow of microbial CP would be expected (Zinn, 1987; Zinn, 1990b; Barajas and Zinn, 1998) and can increase serum insulin, as demonstrated in steers fed isonitrogenous diets containing 30 or 40% ruminally undegraded protein (Froetschel et al., 1997). Ruminal acetate:propionate of steers fed SF28 was likely decreased compared with that of steers fed DR42 (Zinn et al., 1995; Barajas and Zinn, 1998), and infusions of propionate at physiological levels into the rumen (Gonda et al., 1997), mesenteric vein (Sano et al., 1995), or portal vein (Leuvenink et al., 1997) of fed sheep have increased serum insulin.

The marked decrease in insulin for steers fed SF20 in Exp. 1 is intriguing. The percentage decrease in serum insulin of steers fed SF20 compared with steers fed

SF28 was similar on d 28 and 140 (40 and 45%, respectively). This response was accompanied by similar ADG on d 28 and decreased (11.4%) ADG on d 140 among steers fed SF28 and SF20. Because blood samples were collected before feeding and at 4 and 8 h after feeding, evaluating this insulin response using a more intensive sampling interval is needed. The numerical decrease in serum insulin (9.5%) at the end of the feeding period in Exp. 2 for steers fed SF20 compared with those fed SF28 also was accompanied by a numerical decrease in ADG (2.3%). Blood samples were collected once before feeding from two animals per pen in Exp. 2; therefore, it is not known whether more intensive sampling intervals (similar to Exp. 1) or sampling all animals in each pen in Exp. 2 would alter the present results.

Increasing the duration of exposure to steam has linearly increased intestinal flow of nonammonia N (5%), primarily via increased microbial N flow (Zinn, 1990b). Moreover, previous extrapolation of the results of Zinn (1990a) to the present Exp. 1 suggests that MP supply was not decreased as degree of processing increased. These data suggest that insulin decreased despite potentially increased or similar MP supply of steers fed SF28 and SF20. It is possible that small intestinal glucose absorption may have influenced serum insulin. Kreikemeier et al. (1991) reported increased arterial glucose concentration (6 mg/dL) and portal glucose flux (insulin not determined) for steers abomasally infused with 600 g/d (60 g/h) of corn dextrin compared with those fed alfalfa hay. In contrast, Lozano et al. (1995) indicated that portal glucose flux was similar for steers fed .44, .36, or .28 kg/L steam-flaked sorghum. Serum insulin tended to be increased for lactating cows infused with starch hydrolysate (1,500 g/d, 68 g/h) into the abomasum compared with those infused into the rumen (.43 vs .53 ng/mL), whereas serum glucose concentration was similar between treatments (Knowlton et al., 1998). Assuming ruminal starch digestibility (Zinn, 1990a; Zinn et al., 1998) and small intestinal starch disappearance (Owens et al., 1986; Zinn, 1990a) increased as degree of processing increased in Exp. 1, it seems that potential differences in small intestinal starch disappearance between SF28 and SF20 would have a minimal influence on serum insulin.

Alternatively, other endocrine or metabolic factors might be involved in the observed decreased serum insulin for steers fed SF20. Bigner et al. (1996) reported decreased serum insulin (15%) and increased serum glucose in response to a glucose (i.v.) challenge by cows experiencing mild metabolic acidosis (blood pH = 7.33). Metabolic acidosis was produced by feeding ammonium chloride; however, the extent to which the insulin response during hyperchloremic metabolic acidosis reflects the conditions of organic acid load in our experiment is not clear.

The extent to which increased insulin over time of steers in the present experiments reflects increased fat deposition vs tissue insulin resistance also is not clear. Others have reported increased insulin with increasing age, time on feed (Trenkle, 1970; Matsuzaki et al., 1997), and carcass fat content (Trenkle and Topel, 1978). Eisemann et al. (1997) fed a 60% concentrate diet at 2.3% of BW to steers averaging 275 kg and at 2.0% of BW to steers averaging 490 kg to evaluate whole body insulin sensitivity and responsiveness. Heavier steers were older (472 vs 241 d), and carcasses of heavier steers were estimated to contain an increased proportion of fat (12.9 vs 18.5%) and a similar proportion of protein (Eisemann et al., 1996). As steer BW increased at the rate of 1 kg/d, whole body sensitivity and responsiveness to insulin decreased (Eisemann et al., 1997).

Implications

Increasing the degree of corn processing seems to decrease the ash and crude protein content and increase enzymatic starch availability of the resulting product. Results suggest that the optimum rate and efficiency of gain by finishing steers in the present trials occurred when corn was steam-flaked to a bulk density of between .36 and .26 kg/L, which corresponded to starch availability of between 410 and 568 mg of glucose/g of grain DM or 55 to 80% of total starch. Carcass merit, serum metabolites, and urinary nitrogen composition did not seem to be influenced by the degree of corn processing; however, serum insulin might reflect or be involved in mediating the biological responses of cattle fed diets based on processed corn.

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