

Extruded Corn Meal as a Partial Replacement for Steam Flaked Corn in Finishing Diets for Feedlot Cattle: Growth Performance and Digestive Function of Feedlot Cattle

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Abstract

Sixty-four Holstein steers (247 ± 4 kg) were used in a 70-d experiment to evaluate the effects of partial replacement of steam flake corn (SFC) with extruded corn meal (EC) on growth performance and dietary net energy. Treatments consisted of a steam flaked corn-based finishing diet containing 0%, 10%, 20%, or 30% EC, where EC replaced 0%, 15%, 30%, or 45% of SFC (DM basis). Replacement of SFC with increasing levels of EC did not affect ($P > 0.10$) ADG, DMI, and gain efficiency. When EC replaced 15% to 30% of SFC, observed dietary NE was 99% of expected. Whereas, when EC replaced 45% of SFC, observed dietary NE was 94% of expected. Four Holstein steers (210 ± 7 kg) with cannulas in the rumen and proximal duodenum were used in a 4×4 Latin square experiment to evaluate treatment effects on characteristics of digestion. Partial replacement of SFC with EC did not affect ($P > 0.10$) flow of undegraded feed N and microbial N and to the small intestine, and ruminal microbial N efficiency (g microbial N/kg OM fermented). Likewise, there were no treatment effects ($P > 0.10$) on ruminal digestion of OM, NDF, starch and feed N. As expected, total tract digestion of starch for all treatments exceeded 99%. However, partial replacement of SFC with EC decreased total tract digestion of DM and OM (linear effect, $P = 0.02$), and dietary DE (linear effect, $P = 0.03$). These effects were more pronounced where EC replaced 45% of SFC. Partial replacement of SFC with EC did not affect ($P > 0.10$) ruminal pH, total VFA concentration, molar proportions of acetate, propionate, and butyrate, and estimated methane production. It is concluded that partial replacement of SFC with EC does not have a beneficial ef-

fect on ruminal microbial efficiency and digestive function. The feeding value of extruded corn for feedlot cattle is comparable to that of steam flaked corn provided the inclusion rate does not exceed 20% of diet dry matter.

Keywords

Corn Grain, Extruded, Steam Flaked, Feedlot, Cattle

1. Introduction

The objective of grain processing is to improve feeding value and acceptability without detrimentally affecting digestive function [1]. Steam flaking corn can maximize its feeding value, largely due to enhancement of both ruminal and post-ruminal starch digestion [2] [3] [4]. Grain extrusion is a process by which ground grain is preconditioned with steam before being forced through perforated die and cut to size. Like steam flaking, extruding corn disrupts the starch matrix. Matsushima [5] proposed that extruded grains are comparable to steam-flaked grains. However, the effects of extrusion are generally more intense, resulting in a greater degree of chemical and structural transformations, including protein denaturation and starch gelatinization [6] [7], greatly enhancing starch enzymatic reactivity [8] [9]. In a direct comparison of dry rolled vs extruded corn (79% of diet DM), Gaebe *et al.* [10] observed that extruded corn markedly depressed DMI and ADG of feedlot steers. Depressed intake was attributed to protracted low ruminal pH of steers fed extruded corn. In a companion digestion trial, they observed that whereas extrusion markedly increased (13%) starch digestion, diet DE was not improved. This was attributed to low ruminal pH and negative associative effects on digestion of other dietary ingredients. Nevertheless, ruminal *in situ* comparisons demonstrated that rate of starch disappearance over time was more gradual for extruded corn vs ground corn [10]. The provision of fermentable substrate over a more prolonged period of time could have positive implications on ruminal microbial efficiency. The objective of the present study was to evaluate potential positive associative effects of extruded corn, when fed as only a partial replacement for steam flaked corn, on growth performance and characteristics of digestion in feedlot cattle.

2. Materials and Methods

All procedures involving animal care and management were in accordance with and approved by the University of California, Davis, Animal Use and Care Committee.

2.1. Experiment 1, Growth Performance and Dietary Energetics

Sixty-four Holstein steers with an average weight of 247 ± 4 kg were used in a 70-d experiment to evaluate the effects of partial replacement of steam flaked

corn (SFC) with extruded corn meal (EC; Matrix Nutrition, Chandler, AZ) in a finishing diet on growth performance and dietary net energy. Steers were blocked by initial weight into four weight groupings, and randomly assigned within weight groupings to 16 pens (4 steers per pen). Pens were 43 m² with 22 m² of overhead shade, automatic waters, and 2.4 m fence-line feed bunks. Treatments consisted of a steam flaked corn-based finishing diet containing 0%, 10%, 20%, or 30% EC, where EC replaced 0%, 15%, 30%, or 45% of SFC (DM basis). The SFC was prepared as follows. A chest situated directly above the rollers (46 × 61 cm corrugated) was filled with corn and then brought to a constant temperature at atmospheric pressure of 102°C using steam. Corn was steamed for approximately 20 min before starting the rollers. The first approximately 441 kg of steam-flaked grain was allowed to pass from the rollers before material was collected for use in the trial. This preliminary period served for warming the rolls and for adjusting the tension on the rolls to provide a flake density of 0.31 kg/L (24 lbs/bushel). The SFC was then allowed to air-dry for 3 days before feeding. Ingredient and nutrient composition of experimental diets are shown in **Table 1**. Diets were prepared at weekly intervals and stored in plywood boxes located in front of each pen. Steers were allowed ad libitum access to their experimental diets. Fresh feed twice daily at 06:00 and 14:00 h, allowing for approximately 5% residual. All steers were provided ad libitum access to water. Individual steers were weighed upon initiation and completion of the trial. In the calculation of steer performance live weights were reduce 4% to adjust for digestive tract fill. Estimates of steer performance were based on pen means.

Energy gain (EG) was calculated by the equation: $EG = ADG^{1.097} \cdot 0.0557 W^{0.75}$, where EG is the daily energy deposited (Mcal/d), W is the mean shrunk body weight (kg; [11]). Maintenance energy (EM) was calculated by the equation: $EM = 0.084 W^{0.75}$ [12]. Dry matter intake (DMI) is related to EM and dietary NEm according to the equation: $DMI = EM/NEm + EG/(0.877 NEm - 0.41)$, and can be resolved for estimation of dietary NEm by means of the quadratic formula: $x = [-b \pm (b^2 - 4ac)^{0.5}]/2a$, where $x = NEm$, $a = -0.877 DMI$, $b = 0.877 EM + 0.41 DMI + EG$, and $c = -0.42 EM$ [13]. Dietary net energy for gain (NEg) was derived from NEm by the equation: $NEg = 0.877 NEm - 0.41$ [13].

Pens were used as experimental units. The experimental data were analyzed as a randomized complete block design experiment according to the following statistical model:

$$Y_{ij} = \mu + B_i + T_j + E_{ij}$$

where μ is the common experimental effect, B_i represents initial weight group effect (df = 3), T_j represents dietary treatment effect (df = 3), and E_{ij} represents the residual error (df = 9). Treatments effects were tested using the linear, quadratic and cubic polynomials (Statistix 10, Analytical Software, Tallahassee, FL).

2.2. Experiment 2, Digestive Function of Steers

Four Holstein steers (210 ± 7 kg) with cannulas in the rumen (3.8 cm internal

Table 1. Ingredients and composition of experimental diets fed to steers.

Item	Extruded corn meal, % of DMB ¹			
	0	10	20	30
Ingredient				
Sorghum Sudan, hay	12.00	12.00	12.00	12.00
Yellow grease	3.00	3.00	3.00	3.00
Molasses, cane	4.00	4.00	4.00	4.00
Distillers grains, dried, with solubles	10.00	10.00	10.00	10.00
Steam flaked corn ²	67.53	57.53	47.53	37.53
Extruded corn meal ³	0	10.00	20.00	30.00
Urea	1.30	1.30	1.30	1.30
Limestone	1.70	1.70	1.70	1.70
Rumensin 90, mg/lb	0.0184	0.0184	0.0184	0.0184
Magnesium oxide	0.15	0.15	0.15	0.15
TM salt ⁴	0.30	0.30	0.30	0.30
Nutrient composition, DM basis ⁵				
Dry matter, %	88.8	89.0	89.2	89.4
NEm, Mcal/kg	2.21	2.21	2.21	2.21
NEg, Mcal/kg	1.54	1.54	1.54	1.54
Crude protein, %	14.2	14.2	14.2	14.2
Rumen DIP, %	61.8	61.8	61.8	61.8
Rumen UIP, %	38.2	38.2	38.2	38.2
Ether extract, %	7.10	7.10	7.10	7.10
Ash, %	5.70	5.70	5.70	5.70
NDF, %	18.6	18.6	18.6	18.6
Calcium, %	0.75	0.75	0.75	0.75
Phosphorus, %	0.34	0.34	0.34	0.34
Potassium, %	0.75	0.75	0.75	0.75
Magnesium, %	0.29	0.29	0.29	0.29
Sulfur, %	0.16	0.16	0.16	0.16

¹DMB = Dry matter basis; ²Analyzed chemical composition for crude protein, NDF, starch and soluble (amyloglucosidase reactivity) starch were 8.4%, 10.9% and 72.4%, and 8.6% (DM basis), respectively; ³Analyzed chemical composition for crude protein, NDF, starch and soluble (amyloglucosidase reactivity) starch were 8.7%, 10.3%, 69.8% and 30.9% (DM basis), respectively; ⁴Trace mineral salt contained: CoSO₄, 0.068%; CuSO₄, 1.04%; FeSO₄, 3.57%; ZnO, 1.24%; MnSO₄, 1.07%; KI, 0.052%; and NaCl, 92.96%; ⁵Based on tabular values for individual feed ingredients [12].

diameter) and proximal duodenum [14] were used in a 4 × 4 Latin square experiment to evaluate treatment effects on characteristics of ruminal and total tract digestion. Dietary treatments were the same as indicated for Trial 1 (Table 1) with the inclusion of chromic oxide (2.5 g/kg) as a digesta marker. Steers were maintained in individual pens (5.6 m²) with automatic waters. Diets were fed at

0800 and 2000 h daily. In order to avoid the complications of feed refusals, DMI was restricted to 4.5 kg/d. Experimental periods were 14 d, with 10 d for dietary treatment adjustment and 4 d for collection. Between each experimental period there was a 7-d time-frame to recovery during which all steers were fed the control diet (0% extruded corn meal diet). During collection, duodenal and fecal samples were taken twice daily as follows: day 1, 0750 and 1350 h; day 2, 0900 and 1500 h; day 3, 1050 and 1650 h, and day 4, 1200 and 1800 h. Individual samples consisted of approximately 700 mL of duodenal chyme and 200 g (wet basis) of fecal material. Samples from each steer within each collection period were composited for analysis. During the final day of each collection period, ruminal samples were obtained from each steer via ruminal cannula 4 h after feeding. Ruminal fluid pH was determined on fresh samples. Samples were strained through 4 layers of cheesecloth. Two milliliters of freshly prepared (25 g/100 mL) meta-phosphoric acid was added to 8 mL of strained ruminal fluid. Samples were then centrifuged ($17,000 \times g$ for 10 min), and supernatant fluid was stored at -20°C for VFA analysis. Upon completion of the experiment, ruminal fluid was obtained via the ruminal cannula from all steers and composited for isolation of ruminal bacteria by differential centrifugation [15].

Corn, feed and fecal samples were subjected all or part of the following analysis: DM (oven drying at 105°C until no further weight loss); ash (method 942.05, AOAC [16]), Kjeldahl N (method 984.13, AOAC [17]); aNDFom (Van Soest *et al.* [18] corrected for NDF-ash, incorporating heat stable α -amylase (Ankom FAA, Ankom Technology, Macedon, NY) at 1 mL per 100 mL of NDF solution); chromic oxide [19]; starch content and changes in starch solubility as a result of corn processing were determined using amyloglucosidase [20]. Duodenal samples were subjected the following analysis: DM (oven drying at 105°C until no further weight loss); ash (method 942.05, AOAC [16]), Kjeldahl N (method 984.13, AOAC [17]), ammonia N (method 941.04, AOAC [17]); aNDFom (Van Soest *et al.* [18], corrected for NDF-ash, incorporating heat stable α -amylase (Ankom FAA, Ankom Technology, Macedon, NY) at 1 mL per 100 mL of NDF solution); purines [21]; chromic oxide [19]; and starch [20]. Concentrations of VFA in ruminal fluid were determined by gas chromatography using a DB-FFAP Megabore column (30 m \times 0.530 mm, J & W Scientific, Folsom, CA). Column, inlet and detector temperatures were maintained at 130° , 195° , and 200°C , respectively, with carrier gas (N) flow rate at 20 mL/min.

Total DM flow to the duodenum and fecal excretion were estimated based on marker ratio: the relationship of Cr intake (g) vs. concentration of Cr in duodenal and fecal samples. Microbial organic matter (MOM) and N (MN) leaving the abomasum was calculated using purines as a microbial marker [21]. Organic matter fermented in the rumen was considered equal to OM intake minus the difference between the amount of total OM reaching the duodenum and MOM reaching the duodenum. Feed N escape to the small intestine was considered equal to total N entering the duodenum minus ammonia-N, MN and endogenous N ($0.195 \times \text{BW}^{0.75}$, Ørskov *et al.* [22]). Methane production (mol/mol glu-

cose equivalent fermented) was estimated based on the theoretical fermentation balance for observed molar distribution of VFA [23].

The effects of extruded corn meal level in diet (0, 10, 20, or 30%) on characteristics of digestion in cattle were analyzed as a balanced 4×4 Latin square design experiment:

$$Y_{ijk} = \mu + S_i + P_j + T_k + E_{ijk}$$

where: Y_{ijk} is the response variable, μ is the common experimental effect, S_i is the steer effect, P_j is the period effect, T_k is the treatment effect and E_{ijk} is the residual error. Treatments effects were tested by means of linear and quadratic polynomials (Statistix 10, Analytical Software, Tallahassee, FL).

3. Results and Discussion

As expected, CP, NDF and starch content of EC were similar to that of SFC (104%, 94% and 96%, respectively). In contrast, soluble starch (a measure of disruption of the starch matrix) was markedly (359%) greater for EC (**Table 1**). Both steam flaking and extrusion disrupt the starch granule matrix. However, with extrusion the thermal energy transfer and shear stress are more intense, causing a greater degree of chemical and structural transformations, including protein denaturation and starch gelatinization [6] [7] [8] [9]. With respect to steam flaking, degree of processing (flake density, steaming time, tempering) effects changes in starch enzymatic reactivity and characteristics of digestion [3] [24] [25]. However, the relationship between degree of starch gelatinization/solubility brought on by the extrusion process on characteristics of ruminal and total tract digestion has not been assessed [26].

Treatment effects on growth-performance of feedlot steers and estimated net energy values of dietary treatments are shown in **Table 2**. The primary goal of grain processing is to enhance feeding value and diet acceptability in a manner that will improve growth-performance with minimal detrimental effects on digestive function [1]. Partial replacement of SFC with increasing levels of EC did not affect ($P > 0.10$) ADG, DMI, gain efficiency, and dietary net energy. When SFC replaces dry processed corn in finishing diets, feedlot cattle ADG, gain efficiency and dietary NE are appreciably enhanced [1]. In contrast, substitution of dry rolled corn with EC (79% of diet DM) markedly depressed feedlot cattle ADG and gain efficiency [10]. Depressed intake was attributed to protracted low ruminal pH of steers fed EC. Nevertheless, when EC was fed as only a partial replacement for SFC we did not observe marked negative effects on growth-performance.

Observed dietary NE values for the basal SFC-based diet were in good (97%) agreement with expected based on tabular feed values [12]. When EC replaced 15% to 30% of SFC observed dietary NE was 99% of expected. Whereas, when EC replaced 45% of SFC observed dietary NE was 94% of expected. These numerical differences in observed dietary NE were not statistically appreciable ($P = 0.18$).

Treatment effects on characteristics of digestion are shown in **Table 3**. Partial

Table 2. Influence of partial replacement of steam flaked corn with extruded corn on growth-performance of feedlot steers and net energy value of the diet.

Item	Extruded corn meal, % of DM					Pvalue	
	0	10	20	30	SEM	Linear	Quadratic
BW¹, kg							
Initial	246	247	244	251	1.8	0.23	0.12
Final	340	346	338	343	3.9	0.90	0.93
ADG, kg/d	1.34	1.42	1.35	1.32	0.04	0.55	0.29
DMI, kg/d	6.50	6.69	6.37	6.74	0.14	0.58	0.56
Gain: Feed	0.210	0.210	0.210	0.190	0.006	0.30	0.13
Dietary NE, Mcal/kg							
Maintenance	2.15	2.18	2.19	2.09	0.04	0.38	0.18
Gain	1.48	1.51	1.51	1.42	0.04	0.38	0.18
Observed/expected dietary NE							
Maintenance	0.97	0.99	0.99	0.94	0.02	0.38	0.18
Gain	0.97	0.99	0.99	0.93	0.03	0.38	0.18

¹Initial and final BW reduced 4% to account for digestive tract fill.

Table 3. Influence of partial replacement of steam flaked corn with extruded corn on characteristics of ruminal and total tract digestion.

Item	Extruded corn meal, % of DM					Pvalue	
	0	10	20	30	SEM	Linear	Quadratic
Intake, g/d							
DM ¹	4453	4475	4498	4520			
OM	4224	4246	4269	4292			
NDF	693	706	718	731			
N	97	97	97	97			
Starch	2275	2282	2288	2294			
GE, Mcal/d	19.02	19.12	19.22	19.31			
Leaving abomasum, g/d							
OM	1909	1935	2048	1970	85.5	0.45	0.55
NDF	332	343	351	379	21.7	0.15	0.70
Starch	256	259	284	303	22.5	0.12	0.74
Ammonia N	4.49	4.31	3.62	3.81	0.1	<0.01	0.21
Non-ammonia N	96.5	96.7	104	96.8	3.2	0.60	0.30
Microbial N	57.2	55.3	58.0	57.0	2.3	0.86	0.86
Feed N	28.5	30.6	34.7	29.1	3.5	0.72	0.29
Ruminal digestion, %							
OM	68.4	67.5	65.6	67.4	1.8	0.57	0.49

Continued

NDF	52.1	51.5	51.1	48.2	3.1	0.40	0.72
Starch	88.8	88.6	87.6	86.8	0.009	0.14	0.74
Feed N	70.6	68.4	64.3	70.2	3.6	0.74	0.29
Microbial N efficiency ²	20.0	19.5	20.8	19.8	1.1	0.87	0.81
Protein Efficiency ³	1.00	1.00	1.06	0.99	0.03	0.68	0.30
Fecal excretion, g/d							
DM	840	942	933	1034	42	0.01	0.99
OM	721	810	802	989	40	0.01	0.92
NDF	358	406	383	439	21	0.04	0.85
Starch	9.26	10.3	11.0	16.3	1.81	0.02	0.26
N	26.7	28.4	29.6	31.5	1.6	0.05	0.96
GE, Mcal/d	3.71	4.09	4.10	4.57	0.21	0.02	0.84
Total tract digestion, %							
DM	81.1	79.0	79.3	77.1	0.93	0.02	0.98
OM	82.9	80.9	81.2	79.1	0.93	0.02	0.93
NDF	48.4	42.5	46.7	39.9	2.9	0.13	0.88
N	72.4	70.8	69.5	67.7	1.6	0.06	0.97
Starch	99.6	99.6	99.5	99.3	0.09	0.03	0.30
DE diet (Mcal/kg)	3.44	3.36	3.36	3.26	0.05	0.03	0.85
DE (%)	80.5	78.6	78.6	76.4	1.1	0.03	0.85

¹DMI was restricted to 2.15% of BW daily; ²Microbial N, g/kg OM fermented; ³Nonammonia N flow to the small intestine as a fraction of N intake.

replacement of SFC with EC resulted in a numerically small, but appreciable decrease (linear effect, $P < 0.01$) in flow of ammonia N to the small intestine. However, there were no treatment effects ($P > 0.10$) on flow of non-ammonia N, undegraded feed N and microbial N to the small intestine, and ruminal microbial N efficiency (g microbial N/kg OM fermented). Likewise, there were no treatment effects ($P > 0.10$) on ruminal digestion of OM, NDF, starch and feed N.

As expected, total tract digestion of starch for all treatments exceeded 99%. Notwithstanding, replacing SFC with EC decreased total tract digestion of DM and OM (linear effect, $P = 0.02$), and dietary DE (linear effect, $P = 0.03$). Consistent with Trial 1, the effect was more pronounced where EC replaced 45% of SFC.

Substituting SFC with EC did not affect ($P > 0.10$) ruminal pH, total VFA concentration, molar proportions of acetate, propionate, butyrate and isovalerate, and estimated methane production (Table 4). Ruminal pH (4 hours post-prandial) averaged 5.68 ± 0.03 . Generally, ruminal proteolytic activity does not decrease as pH decrease in cattle fed high-concentrate diets [27]. However, microbial efficiency is affected as greater energy is expended to maintain intracellular pH [28]. Partial replacement of SFC with EC increased (linear effect, $P <$

Table 4. Influence of partial replacement of steam flaked corn with extruded corn on ruminal pH, VFA molar proportions, and estimated methane production¹.

Item	Extruded corn meal, % of DM				SEM	P value	
	0	10	20	30		Linear	Quadratic
Rumen pH	5.69	5.72	5.65	5.65	0.16	0.78	0.92
Total VFA, mM	107	107	107	116	6.57	0.36	0.46
	Rumen VFA, mol/100 mol						
Acetate	52.5	54.8	54.9	49.2	3.54	0.55	0.28
Propionate	33.5	30.4	28.6	33.6	3.44	0.92	0.26
Isobutyrate	0.43	0.53	0.54	0.56	0.10	0.43	0.70
Butyrate	10.7	11.0	12.5	12.2	1.33	0.33	0.83
Isovalerate	1.77	2.28	1.86	2.81	0.46	0.22	0.64
Valerate	1.14	1.03	1.61	1.66	0.14	<0.01	0.57
Acetate: propionate	1.68	2.25	2.00	1.48	0.44	0.67	0.24
Methane ²	0.43	0.47	0.49	0.42	0.05	0.90	0.26

¹DMI was restricted to 2.15% of BW; ²Methane, mol/mol glucose equivalent fermented.

0.01) ruminal molar proportions of valerate. The basis for this is not certain. However, it may reflect the increased denaturation and solubilization of corn protein during the extrusion process, as changes in valerate concentrations reflect ruminal protein degradation. When proline undergoes reductive ring cleavage and deamination it yields valerate [29].

4. Conclusion

Partial replacement of steam flaked corn with extruded corn does not have a beneficial effect on ruminal microbial efficiency and digestive function. The feeding value of extruded corn for feedlot cattle is comparable to that of steam flaked corn provided the inclusion rate does not exceed 20% of diet dry matter.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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