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Influence of processing method on comparative digestion of white corn versus conventional steam-flaked yellow dent corn in finishing diets for feedlot cattle

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ABSTRACT: Four Holstein steers (137 ± 2 kg) with cannulas in the rumen and proximal duodenum were used in a 4 × 4 Latin square design to evaluate the influence of processing method on comparative digestion of white corn. Treatments consisted of a basal finishing diet containing 80% corn grain (DM basis) as 1) dry-rolled white corn (DRWC), 2) steam-flaked white corn (SFWC) with 0.36 kg/L flake density (SFWC36), 3) SFWC, 0.31 kg/L flake density (SFWC31), and 4) steam-flaked yellow corn (SFYC) with 0.31 kg/L flake density (SFYC31). Characteristics of ruminal, postruminal, and apparent total tract digestion of OM, starch, and N were similar ($P \geq 0.08$) for SFYC31 and SFWC31 treatments. Decreasing flake density of white corn (from 0.36 to 0.31 kg/L) did not affect ($P = 0.22$) ruminal OM digestion, but increased (1.9%, $P = 0.07$) apparent total tract OM digestion. Compared with dry rolling, steam flaking white corn increased ruminal (9.4%, $P = 0.05$), postruminal (14.4%, $P < 0.01$), and apparent total tract OM digestion (8.2%, $P < 0.01$), reflecting corresponding increases in ruminal (13.3%, $P < 0.01$), postruminal (43%, $P < 0.01$), and apparent total tract (12.3%, $P < 0.01$) starch digestion. Apparent postruminal and apparent total-tract N digestion also were greater (6.5 and 5.6%, respectively, $P = 0.04$) for SFWC than for DRWC. The DE value of SFWC and SFYC diets was similar, averaging 3.39 Mcal/kg. The DE value of SFWC was greater (8.1%, $P < 0.01$) than that of DRWC. Ruminal pH (4 h postprandial) averaged 5.74 and was not affected ($P \geq 0.48$) by dietary treatments. Compared with dry rolling, steam flaking markedly enhances the feeding value of white corn, with optimal flake density being less than 0.36 kg/L. Although white corn has greater vitreous endosperm content, characteristics of ruminal starch digestion and undegradable intake protein are similar to conventional yellow dent corn when processed to a similar flake density (0.31 kg/L). However, postruminal and apparent total tract starch digestion tends to be slightly less for flaked white corn than for yellow corn.

Key words: digestion, grain processing, steer, white corn

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INTRODUCTION

Corn endosperm and kernel characteristics influence starch and protein digestion (Zinn et al., 2002; Jaeger et al., 2006). As the proportion of vitreous endosperm (vitreousness) increases, rate of ruminal starch degradation decreases (Philippeau et al., 1999a). Compared with yellow corn, white corn has greater (26 to 32%) vitreous endosperm than floury varieties (Philippeau et al., 1999; Centrec Consulting Group LLC, 2009) and, thus, compared with yellow corn, is expected to reduce starch digestion and decrease NE value. In Mexico, white corn hybrids (dry-rolled or steam flaked) constitute a principal domestic feed grain for feedlot cattle. Steam flaking ameliorates corn hybrid effects on starch digestion (Corona et al., 2006), the magnitude of the effect being dependent on corn flake density (Zinn et al., 2002). Very little information is reported in the literature regarding characteristics of digestion of white corn in cattle.

The objective of this study was to determine the influence of processing method on comparative digestion of white vs. yellow corn in finishing diets for feedlot cattle.

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MATERIALS AND METHODS

Animal care and handling techniques were approved by the University of California Animal Care and Use Committee.

Four Holstein steers (137 ± 2 kg) with cannulas in the rumen and proximal duodenum (6 cm from the pyloric sphincter; Zinn and Plascencia, 1993) were used in a 4 × 4 Latin square design experiment. All steers received treatment 1 (Table 1) for 7 d before initiation of the trial. Dietary treatments consisted of a basal finishing diet containing 80% corn grain (DM basis) as 1) dry-rolled white corn (**DRWC**); 2) steam-flaked white corn (**SFWC**), 0.36 kg/L flake density (**SFWC36**); 3) SFWC, 0.31 kg/L flake density (**SFWC31**); and 4) steam-flaked yellow corn (**SFYC**), 0.31 kg/L flake density (**SFYC31**). Density measures were determined using a hand-type density scale (Weight Per Bushel Tester, Mill & Elevatory Supply Co., Kansas City, MO) on freshly processed grain obtained as it exited directly beneath the rolls. Experimental diets are shown in Table 1. Dry-rolled white corn was prepared by passing whole corn through rollers (46 × 61 cm rolls, 5.5 corrugations/cm; Memco, Mills Rolls, Mill Engineering & Machinery Co., Oakland, CA) that had been adjusted so that kernels were broken to a density of 0.50 kg/L. Steam-flaked corn was prepared as follows. A chest situated directly above the rollers (46 × 61 cm rolls, 5.5 corrugations/cm; Memco, Mills Rolls, Mill Engineering & Machinery Co.) was filled to capacity (440 kg) with whole corn and brought to a constant temperature (102°C) at atmospheric pressure using steam (boiler pressure 60 psi). The corn was steamed for 20 min before starting the rollers. Approximately 440 kg of the initial steam-processed grain that exited the rolls during warm-up was not fed to steers on this study. Tension of the rollers was adjusted to provide the indicated flake density (0.31 or 0.36 kg/L). Retention time of grain in the steam chamber was approximately 18 min. The steam-flaked corn was allowed to air-dry (5 d) before use in diet preparation. Yellow corn used was a commercial blend of US #2 dent, whereas white corn was a commercial blend obtained from Sinaloa, Mexico. To determine chemical composition and endosperm fraction of grains tested, dissection was performed according to Corona et al. (2006) by manual dissection of 50 randomly selected, whole kernels from each grain sample. Endosperm fraction obtained was ground through a Wiley mill (1-mm screen) and were analyzed for total starch (Zinn, 1990b) and for N (method 984.13, AOAC, 1986) and ash content (method 942.05, AOAC, 1986). Dry matter intake was restricted to 3.17 kg/d (90% of ad libitum intake by steers at the start of the experiment). Diets were fed in 2 equal proportions at 0800 and 2000 h daily. Chromic oxide (320 g, air-dry basis/t of diet), was premixed with minor ingredients (urea, limestone, and trace mineral salt) before incorporation into complete mixed diets. Experimental periods consisted of a 10-d diet adjustment period followed by a 4-d collection period. During the collection period duodenal and fecal samples were taken from all steers, twice daily as follows: d 1, 0750 and 1350 h; d 2, 0900 and 1500 h; d 3, 1050 and 1650 h; and d 4, 1200 and 1800 h. Individual samples consisted of approximately 500 mL of duodenal chyme and 200 g (wet basis) of fecal material. Samples from each steer and within each collection period were composited for analysis. During the final day of each collection period, a ruminal sample was obtained from each steer 4 h postprandial via the ruminal cannula. Ruminal fluid was taken from ruminal ventral sac by vacuum pump (Cole Parmer Instrument, Vernon Hill, IL) using a Tygon tube (1.90 cm i.d., 3/4 in.; USP, Lima, OH), and pH was determined on fresh samples. Upon completion of the trial, ruminal fluid was obtained from all steers and composited for isolation of ruminal bacteria via differential centrifugation (Bergen et al., 1968). The microbial isolate served as the purine:N reference for estimation of microbial N (**MN**) contribution to chyme entering the small intestine (Zinn and Owens, 1986). Duration of meal (offered in the morning) was registered in each animal in all periods (56 observations per treatment). Recordings were made daily visually upon when the meal was eaten. The arbitrary criteria for determining when a meal was eaten was that at least 90% of the morning feed offered was consumed. Samples were subjected to all or part of the following analysis: DM (oven drying at 105°C until no further weight loss; method 930.15, AOAC, 1986); ash (method 942.05, AOAC, 1986); Kjeldahl N (method 984.13, AOAC, 1986); ammonia N (method 941.04, AOAC, 1986); purines (Zinn and Owens, 1986); GE (adiabatic calorimeter bomb, model 1271, Parr, Moline, IL); chromic oxide (Hill and Anderson, 1958); and starch (Zinn, 1990b). Microbial OM and MN leaving the abomasum were calculated using purines as a microbial marker (Zinn and Owens, 1986). 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 microbial OM reaching the duodenum. Feed N escape to the small intestine was considered equal to total N leaving the abomasum minus ammonia-N and MN and, thus, includes any endogenous contributions. The trial was analyzed as a 4 × 4 Latin square design (Morris, 1999). The statistical model for the trial was as follows:

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

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. Treatment effects were tested for the following orthogonal components: 1) SFYC31 vs. SFWC31, 2) SFWC31 vs. SFWC36, and 3) SFWC vs. DRWC. Statistical relationship between meal duration and ruminal pH (measured 4 h postprandium) was determined using regression analysis (Statistix, Analytical Software, Tallahassee, FL). Contrasts were considered significant

Table 1. Composition of experimental diets (DM basis)

	Treatment[1]			
Item	SFYC31	SFWC31	SFWC36	DRWC
Ingredient, %				
Alfalfa hay	8.00	8.00	8.00	8.00
Sudangrass hay	4.00	4.00	4.00	4.00
SFYC (0.31 kg/L)	80.00			
SFWC (0.31 kg/L)		80.00		
SFWC (0.36 kg/L)			80.00	
DRWC				80.00
Cane molasses	2.00	2.00	2.00	2.00
Yellow grease	2.00	2.00	2.00	2.00
Urea	1.60	1.60	1.60	1.60
Limestone	1.50	1.50	1.50	1.50
Trace mineral salt[2]	0.40	0.40	0.40	0.40
Magnesium oxide	0.20	0.20	0.20	0.20
Chromic oxide	0.30	0.30	0.30	0.30
Nutrient composition,[3] DM basis				
NE_m, Mcal/kg	2.21	2.21	2.21	2.21
NE_g, Mcal/kg	1.55	1.55	1.55	1.55
CP, %	12.30	13.96	13.89	13.60
Ether extract, %	5.70	5.70	5.70	5.70
Ca, %	0.70	0.70	0.70	0.70
P, %	0.28	0.28	0.28	0.28

[1]SFYC = steam-flaked yellow corn, density of 0.31 kg/L; SFWC = steam-flaked white corn, density of 0.31 or 0.36 kg/L; DRWC = dry-rolled white corn.

[2]Trace mineral salt contained the following: $CoSO_4$, 0.068%; $CuSO_4$, 1.04%; $FeSO_4$, 3.57%; ZnO, 1.24%; $MnSO_4$, 1.07%; KI, 0.052%; and NaCl, 92.96%.

[3]The estimation was based on tabular values for individual feed ingredients (NRC, 1996) with the exception of CP, which was determined in our laboratory.

when the *P*-value was ≤0.05, with a *P*-value of ≤0.10 considered as a tendency approaching significance.

RESULTS AND DISCUSSION

Average starch content of yellow corn (68%) was slightly (4.4%) less (Table 2) than the average value of 71% reported by Zinn et al. (2002), but is in the range (61 to 78%; mean 71.1%) reported by White and Pollack (1995). Consistent with previous studies (FAO, 1992; Cravero et al., 2003; Sánchez et al., 2007), white corn grain contained slightly less (3.3%) starch, but greater N (19%) than yellow corn, reflecting the greater (23%) vitreous endosperm content of white corn. In agreement with prior summaries (FAO, 1992; Zinn and Owens, 2008), weight distribution of principal kernel components (Table 2) for white and yellow corn hybrids averaged 4.5, 2.6, 8.3, and 84.8% for pericarp, tip cap, germ, and total endosperm, respectively.

Treatments effects on ruminal pH 4 h postprandium, rate of feed intake, and site and extent of digestion are shown in Table 3. Ruminal pH averaged 5.74 and

Table 2. Characteristics of grain and proportions of parts of corn kernel used in the trial

Item	Yellow corn	White corn	SD
100-grain weight,[1] g (DM)	32.02	34.33	1.41
Chemical composition, % of DM			
Starch	67.71	65.73	—
N	1.30	1.61	—
Endosperm N	6.60	5.62	—
Ash	1.43	1.33	—
Structural composition,[2] % of kernel DM			
Pericarp	4.33	4.56	0.32
Tip cap	2.51	2.59	0.53
Germ	8.81	7.71	0.61
Endosperm	84.35	85.14	0.40
Endosperm composition,[2] % of total endosperm DM			
Vitreous endosperm	57.04	70.03	3.61
Floury endosperm	42.96	29.97	2.12

[1]Average of 100 randomly selected whole kernels from each grain sample.

[2]Average of 50 randomly selected whole kernels from each grain sample.

was not affected by treatment. Observed ruminal pH 4 h postprandium was consistent with predicted average pH (5.70) for the feeding interval based on diet formulation (Table 1; NRC, 1996, Level 1). That corn processing method (dry rolling vs. steam flaking to a density of 0.31 kg/L) did not affect ruminal pH 4 h postprandium is congruent with previous studies (Barajas and Zinn, 1998; Zinn et al., 1998). Although Zinn (1990a) observed that the effects of steam flaking on ruminal pH 4 h postprandium was proportional to flake thickness.

Eating duration per meal was greater (16.7%, P = 0.02) for DRWC than for SFWC. Across treatments, rate of feed consumption averaged 9.6 ± 0.8 min/kg of DMI. This rate of DMI is consistent with previously reported range of 4 to 10 min/kg (Welch and Hooper, 1988; Grant and Albright, 2000).

There were no corn hybrid or processing effects on apparent ruminal degradation of feed N or ruminal MN efficiency, averaging 57.6% and 20.1 g (duodenal MN, g/kg of OM fermented in the rumen), respectively. In the same manner, there were no effects of corn processing on ruminal protein efficiency (duodenal nonammonia N leaving abomasum/N intake). In previous studies no differences were detected by processing of corn on protein efficiency (Corona et al., 2006), but in others

Table 3. Treatment effects on characteristics of feed intake and digestion in cannulated Holstein steers (137 kg of BW)[1]

						Contrast P-value		
Item	SFYC31	SFWC31	SFWC36	DRWC	SEM	SFYC31 vs. SFWC31	SFWC31 vs. SFWC36	SFWC vs. DRWC
Ruminal pH[2]	5.62	5.74	5.84	5.78	0.152	0.48	0.61	0.97
Meal duration,[3] min/feeding	28.1	30.7	29.1	34.9	2.23	0.64	0.81	0.02
Intake, g/d								
DM	3,153	3,177	3,151	3,216				
OM	2,992	3,003	2,963	3,049				
Starch	1,749	1,522	1,417	1,687				
N	62	71	70	70				
GE, Mcal/d	13.1	13.1	13.0	13.3				
Flow to duodenum, g/d								
OM	1,513	1,555	1,439	1,689	61.1	0.64	0.23	0.04
Starch	273	258	230	466	23.6	0.66	0.44	<0.01
Nonammonia N	65	67	67	64	3.5	0.77	0.91	0.48
Microbial N	40	35	36	35	3.5	0.43	0.90	0.89
Feed N	26	31	31	29	2.8	0.20	0.98	0.47
Ruminal digestion, %								
OM	62.6	60.0	63.6	56.1	1.87	0.35	0.22	0.05
Starch	84.4	83.1	83.7	72.4	1.56	0.56	0.77	<0.01
Feed N	58.9	55.9	55.8	59.5	4.00	0.61	0.97	0.48
Microbial efficiency[4]	21.1	19.6	19.0	20.5	1.88	0.60	0.83	0.63
Protein efficiency[5]	1.04	0.90	0.91	0.99	0.051	0.19	0.84	0.48
Fecal excretion, g/d								
DM	515	516	567	750	18.1	0.97	0.09	<0.01
OM	433	423	462	668	14.9	0.62	0.10	<0.01
Starch	31	58	44	258	9.8	0.10	0.35	<0.01
N	17	19	20	22	0.8	0.09	0.71	0.03
GE, Mcal/d	2.36	2.27	2.44	3.28	0.101	0.56	0.27	<0.01
Postruminal digestion, % leaving abomasum								
OM	71.5	72.8	67.8	60.3	1.17	0.44	0.03	<0.01
Starch	88.4	75.9	80.7	44.3	4.17	0.08	0.45	<0.01
N	74.4	71.2	70.5	66.2	1.32	0.13	0.70	0.03
Apparent total tract digestion, %								
DM	83.7	83.7	82.0	76.7	0.57	0.92	0.08	<0.01
OM	85.5	85.9	84.4	78.1	0.51	0.59	0.07	<0.01
Starch	98.2	96.2	96.8	84.7	0.63	0.06	0.45	<0.01
N	72.5	72.7	71.8	68.2	1.21	0.93	0.65	0.04
DE, %	81.9	82.8	81.3	75.4	0.79	0.50	0.24	<0.01
DE, Mcal/kg	3.39	3.42	3.36	3.12	0.033	0.50	0.24	<0.01

[1]SFYC = steam-flaked yellow corn, density of 0.31 kg/L; SFWC = steam-flaked white corn, density of 0.31 or 0.36 kg/L; DRWC = dry-rolled white corn.

[2]Measured at 4 h postprandium (morning meal).

[3]Lecture was taken in morning feeding. Finish of meal was considered when animals fed at least approximately 90% of total meal offered.

[4]Duodenal microbial N, $g \cdot kg^{-1}$ OM fermented in the rumen.

[5]Duodenal nonammonia N, $g \cdot g^{-1}$ N intake.

(Zinn et al., 1995; Barajas and Zinn, 1998) protein efficiency was greater for steam-flaked corn than for dry-rolled corn. In those cases, the increase in protein efficiency was due to increased MN synthesis related to increased ruminal OM digestion. Expected ruminal degradation of feed N and ruminal microbial efficiency based on NRC (1996) Level 1 was 56.7%, and 24.0 g of N/kg of OM fermented, respectively. Adjusting apparent ruminal degradable feed N for endogenous contributions to N flow to the small intestine (0.195 g/kg of $BW^{0.75}$; Ørskov et al., 1986), true ruminal degradation of dietary CP was 66.9%, 97% of expected based on NRC (1996, Level 1). Given that the ruminal degradability of the other protein-containing ingredients of the basal diet (alfalfa, sudangrass, and cane molasses) were consistent with NRC (1996), then by difference, the undegradable intake protein (**UIP**) values for DRWC, SFWC36, SFWC31, and SFYC31 were 46, 52, 52, and 49%, respectively. These UIP estimates are consistent with previous estimates for corn protein (53%, Zinn et al., 1981) and are within the tabular range of 46 to 55% proposed by NRC (1996). Thus, notwithstanding the greater (23%) vitreousness of white corn, UIP was not affected.

Likewise, despite differences in endosperm vitreousness, ruminal starch digestion was similar for SFYC31 and SFWC31. However, postruminal starch digestion tended to be greater (16%, $P = 0.08$) for SFYC31 than for SFWC31, resulting in a tendency for slightly greater (2%, $P = 0.06$) apparent total tract starch digestion, suggesting that corn vitreousness may have a practical impact on postruminal starch digestion.

The ameliorating effect of steam flaking on differences in starch digestion due to corn vitreousness has been reported previously (Corona et al., 2006). Likewise, Szasz et al. (2007) observed that differences in corn vitreousness did not affect site and extent of starch digestion in steers feed high-moisture corn-based finishing diets.

Decreasing flake density (from 0.36 to 0.31 kg/L) of white corn did not affect ruminal OM digestion or site and extent of starch digestion. However, reducing the flake density of white corn increased postruminal (6.9%, $P = 0.03$) and tended to increase apparent total tract (1.9%, $P = 0.07$) OM digestion, a characteristic response to decreasing corn flake density (Zinn, 1990a; Zinn et al., 2002).

Compared with dry rolling, feeding SFWC increased ruminal (9.4%, $P = 0.05$), postruminal (14.4%, $P < 0.01$), and apparent total tract OM digestion (8.2%, $P < 0.01$). The improvement in apparent total tract OM digestion was in close agreement to the 8.1% reported by May et al. (2009) in a comparison of DRYC vs. SFYC. Barajas et al. (2006) reported a 7% increase in apparent total tract OM digestion due to steam flaking white corn.

Ruminal and apparent total tract starch digestion for SFWC averaged 83.4 and 97.2%, respectively. Consistent with previous studies (Owens and Zinn, 2005; Corona et al., 2006; Zinn and Owens, 2008) comparing SFYC vs. DRYC, steam flaking increased ($P < 0.01$) ruminal (13.3%), postruminal (43.4%), and apparent total tract (12.3%) starch digestion. Improvements due to steam flaking on postruminal and apparent total tract starch digestion were associated with increased apparent postruminal (6.5%; $P = 0.03$) and apparent total-tract (5.6%; $P = 0.04$) N digestion. In as much as starch granules are encapsulated in an increased UIP protein matrix comprising roughly 89% of corn protein (Watson, 2003), the association between increased postruminal digestibility of starch and increased postruminal digestibility of N is expected.

Digestible energy was greater (7.9%; $P < 0.01$) for steam-flaked than for dry-rolled corn-based diets. If all the improvement in DE with steam flaking were due solely to increased starch digestion, then the expected increase in DE would be 8.3%, [(4.15*(0.965 − 0.847)*0.657)]/3.87, where 4.15 is the GE (Mcal/kg) value of starch, 0.965 and 0.847 are the observed apparent total tract starch digestion coefficients (g/kg) for SFWC and DRWC diets, respectively, 0.657 is the proportion (g/kg) of starch in white corn (Table 2), and 3.87 is the DE value (Mcal/kg) for dry corn grain (NRC, 1996)]. This improvement, due to changes in starch digestion alone, is 46% greater than the 5.7% increase in DE (4.09 vs. 3.87 Mcal/kg of DE) due to steam flaking conventional yellow corn indicated by NRC (1996).

Given that the DE value of SFYC corn is 4.25 (Zinn et al., 2002), the DE values of white corn treatments can be estimated using the replacement technique (Zinn, 1990b): DE, Mcal/kg of test corn = [(DE of test corn diet − DE of SFYC diet)/0.80] + 4.25. The constant 0.80 represents the amount of corn in the diet. Accordingly, the DE values of DRWC and SFWC are 3.91 and 4.25 Mcal/kg, respectively. Corresponding NE_m and NE_g values (Zinn, 1990a) are, respectively, 2.20 and 1.52 Mcal/kg for DRWC and 2.44 and 1.73 Mcal/kg for SFWC. Accordingly, changes in starch digestion due to processing explained 95% of the variation in energy value of white corn. Net energy values for DRWC and SFWC are consistent with previous values obtained for yellow corn (Zinn et al., 1995, 2002; Corona et al., 2005, 2006). The 8.3% increase in energy value of white corn due to steam flaking is within of the range improvement of 8.1 to 19.2% reported for yellow corn in previous metabolism trials (Zinn et al., 1995, 2002; Corona et al., 2005, 2006). As discussed in previous reports (Zinn et al., 2002), the NRC (1996) overestimates the NE value of dry-rolled corn in the range of 5 to 10%.

In light of the greater (23%) vitreous endosperm concentration of white corn, the similarity in energy value of DRWC with tabular values for DRYC was surprising. In previous studies (Correa et al., 2002; Ngonyamo-Majee et al., 2008), a strong negative relationship was observed between endosperm vitreousness and in situ starch and DM degradability of dry-processed corn. Allen et al. (2008), evaluating 2 corn hybrids containing 25 or 66% vitreous endosperm in cannulated lactating dairy cows, observed that ruminal and apparent total tract starch digestion was less (19.1 and 7.1%, respectively) for the 66% vitreous endosperm hybrid.

Compared with dry rolling, steam flaking markedly enhances the feeding value of white corn. Although white corn has greater vitreous endosperm content, characteristics of ruminal starch digestion and UIP are similar to conventional yellow dent corn when processed to a similar flake density (0.31 kg/L). However, postruminal and apparent total tract starch digestion tends to be slightly less for flaked white corn than for yellow corn.

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