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Influence of Tempering and Steaming Requirements of Flaked Corn for Feedlot Cattle Diets

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Abstract: Five trials were conducted to evaluate the influence of tempering and time, delivery rate and pressure of steam on the feeding value of Steam-Flaked Corn (SFC) for feedlot cattle. Trial 1, 4 Holstein steer with cannulas in the rumen and proximal duodenum were used in a 4×4 Latin square design. Treatments were: Dry Rolled Corn, no steam (DRC); Tempered Rolled Corn, no steam (TRC), tempered flaked corn, 5 min steaming time (T-5 min-SFC) and flaked corn, 25 min steaming time (25 min-SFC). There were no treatments effects ($p>0.10$) on ruminal digestion of OM, DIP and ruminal microbial efficiency. There was a tendency ($p = 0.19$) for ruminal NDF digestion to be lower for 25 min-SFC than for T-5 min-SFC. Ruminal starch digestion was greater (14.1%, $p<0.05$) for steam-flaked corn treatments than for rolled corn treatments. Ruminal N efficiency tended to be greater ($p = 0.13$) for steam flaked corn treatments then for rolled corn treatments. Post ruminal and total tract digestion of OM, starch and N were greater ($p<0.05$) for steam-flaked corn treatments than for rolled corn treatments (36.8 and 19.3%, respectively). Ruminal pH was lower (4.8%, $p<0.05$) for steam-flaked corn treatments than for rolled corn treatments. Ruminal acetate: propionate molar ratios and estimated methane production were also lower for steam-flaked corn treatments than for rolled corn treatments. In trial 2, eighty crossbred heifers (248 kg BW) were used in a 105 day randomized complete block design experiment to evaluate treatment effects: No tempering and 117 kPa of steam pressure (NT117); no tempering and 379 kPa of steam (NT379); Tempering and 117 kPa of steam (T117) and Tempering and 379 kPa of steam pressure (T379). There were no treatment effects ($p>0.10$) on ADG, DMI, gain efficiency, or dietary NE. In trial 3, 4 Holstein steer with ruminal and duodenal cannulas were used in a 4×4 Latin square to evaluate characteristics of digestion of dietary treatment fed in trial 2. Tempering did not affect ($p>0.10$) ruminal digestion of OM, starch, or N. However, it increased ($p<0.05$) post ruminal and total tract digestion of OM (3.4 and 1.4%, respectively) and N (0.6 and 3%, respectively). Increasing steam pressure from 117-379 kPa increased ($p<0.05$) post ruminal (3.8%) and total tract starch digestion (0.8%). Ruminal and total tract starch digestion averaged 82 and 98%, respectively. In trial 4, 96 crossbred steer calves (347 kg BW) were used in a 56 day trial to evaluate treatment effects on performance and dietary NE value. Treatments were: no tempering and 419 kPa along a 6.35 diam steam line, measured 90 cm proximal to steam chest splitter valves. (NT419); no tempering and 335 kPa of steam (NT335); tempering and 419 kPa of steam (T419) and tempering and 335 kPa of steam pressure (T335). There were no treatment effects ($p>0.20$) on ADG (1.24 kg day^{-1}), DM conversion (5.60 kg DM kg^{-1} ADG) and dietary NE for maintenance and gain (2.24 and 1.55 Mcal kg^{-1}, respectively). In trial 5, 4 Holstein steer with ruminal and duodenal cannulas were used in a 4×4 Latin square design to evaluate characteristics of digestion of dietary treatments fed in trial 4. Percentage of corn starch that was reactive to amylglucosidase (a measure of starch solubility) was similar across SFC treatments, averaging 22%. Ruminal digestion of OM averaged 65.0% and was not affected ($p>0.20$) by treatments. Tempering increased (4.6%, $p<0.05$) ruminal starch digestion. However, ruminal starch digestion was not influenced by steam reduction (80.7 vs 80.4%, $p>0.20$). Total tract digestion of OM and starch also were not affected ($p>0.20$) by treatments, averaging 68.3 and 97.7%, respectively. We conclude that optimal feeding value can be achieved from flaked corn using considerably less steam than is

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customary in the industry. However, under conditions of lower steam delivery rates, more than 50 min tempering time may be required to soften the corn sufficiently to maintain high roller output rates. Provided that the lower quarter of the steam chest is maintained at temperature greater than 100°C, reducing steam application by as much as 20% will not detrimentally affect the feeding value of SFC.

Key words: Steam flaked corn, tempering, cattle, digestion and performance

INTRODUCTION

Steam Flaking (SF) increases the NE value of corn by 13-19% over that of Dry Rolling (DR) (Barajas and Zinn, 1998; Zinn *et al*., 2002; Corona *et al*., 2006). Most of the additional costs of flaking vs dry rolling corn are associated with steam production. Objectives of steaming are to sterilize the grain (kill weed seed), restore moisture, temper (soften) the kernel and cook the starch. Very little research has been reported on methods for optimizing the steaming process. Hence, steaming practices are based primarily on convention rather than science. Exposing corn to steam at atmospheric pressure for 12 min will increase its moisture content by 3-5% (Johnson *et al*., 1968; Beeson, 1972), but greater than 50 min steaming time may be required to increase the moisture content of corn by more then 5% units (Zinn, 1990b). Wetting agents or surfactants can be added along with water to corn prior to steaming (tempering) in order to accelerate the rate of moisture uptake by the kernel (Zinn, 1988). Added moisture may also increase the efficiency of heat transfer during the steaming, thereby decreasing the necessary steaming time. However, the amount, time and site of the injected steam into the steam chamber, in combination with tempering to increase the uptake of moisture by the grain has received little attention (Zinn, 1988; Salinas *et al*., 1999; Zinn *et al*., 2000). In preliminary work with tempering we observed that if tempered corn was processed immediately following steam flaking (the steam chamber was completely empty, but the rolls were still very hot) the initial output of rolled tempered corn appeared very much like steam flaked corn, even though no steam was being injected into the chamber. Following up on this we observed that we could simulate the process (maintain hot rolls) by opening the steam inlet closest to the rolls and turning off the other valves that inlet steam to the steam chamber. Accordingly, with only about 20% the steam that we normally use in flaking corn we were able to produce flaked corn. Because of the short exposure time of the corn to the tempering process (55 min total) the floury endosperm was still a little dry. But, the outer horny endosperm took on the characteristic amorphous appearance of steam flaked corn. The objectives of the studies reported herein were to evaluate the effects of tempering and parameters of steam injection on the feeding value of flaked corn in diets fed to feedlot cattle.

MATERIALS AND METHODS

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

Trial 1: Effects of tempering and steaming time of steam-flaked corn on characteristics of digestion: Four Holsteins steers (average BW: 238 kg) with cannulas in the rumen and proximal duodenum (Zinn and Plascencia, 1993) were used in a 4×4 Latin square experiment. Four corn processing treatments were compared: Dry Rolled Corn (DRC); Tempered Rolled Corn (TRC), tempered with 5 min steaming time, flaked corn (T-5 min-SFC) and 25 min steam time, flaked corn (25 min-SFC, conventional steam-flaked corn). The DRC treatments were prepared by passing corn through rollers (46×61 cm rolls, 5.5 corrugations/cm; Memco Mill Rolls, Mill Engineering and Machinery Co., Oklahoma, CA) that had been adjusted so that kernels were broken to a density of 0.50 kg L^{-1}. The TRC was prepared as follows: water (0.075 L kg^{-1} corn) plus tempering agent (0.15 mL kg^{-1} SarTemp®, SarTec Corp., Anoka, MN) were sprayed on corn as it was augered into a holding bin located directly above the steam chest. Retention time of corn in the holding bin was approximately 30 min. Retention time of corn in the steam chest was approximately 25 min. The 25 min-SFC was prepared as follows: A chest situated directly above the rollers was filled to capacity (440 kg) with corn and brought to a constant temperature (102°C) at atmospheric pressure using steam (boiler pressure, was set at 483 kPa). The corn was steamed for 25 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 rolls was adjusted to provide a flake density of 0.31 kg L^{-1}. Retention time of grain in steam chamber was set at approximately 25 min. There are 6 steam inlets to the steam chamber. The 6th or uppermost inlet value was not opened (to reduce steam entering the upper holding bin just above the steam chamber). Also, the 1st or lowermost inlet valve located closest to the rolls is only partially opened to prevent steam wastage and grain blowing off the feeder bar. The T-5 min-SFC was prepared in a manner similar to that of TRC, except that a steam inlet that permits the injection of steam directly onto the rolls was opened. The 1st steam inlet on the steam chamber, just above the rolls, was also partially opened. All other steam inlets were closed. Because of the brief steaming time of corn prior to flaking, the floury endosperm of the kernel for T-5 min-SFC was still a little dry. Hence, flaking the corn to 0.31 kg L^{-1} made the flake too fragile. Consequently, we increased the bulk density of the T-5 min-SFC to 0.36 kg L^{-1}. The various processing treatments were allowed to air-dry (2 day) before use in diet preparation. The basal diet contained (DM basis, g kg^{-1}): 721.5 processed corn treatment, 140.0 sudangrass hay, 40.0 yellow grease, 60.0 cane molasses, 12.0 urea, 16.0 limestone, 1.5 magnesium oxide, 4.0 chromic oxide and 5.0 trace mineral sale. Chromic oxide was added as a digest marker. Steers were maintained in individual pens with access to water at all times. Diets were fed at 0800 and 2000 daily. Dry matter intake was restricted to 5.6 kg day^{-1}. Experimental periods consisted of a 10 day diet adjustment period followed by a 4 day collection period. During the collection period duodenal and fecal samples were taken from all steers, twice daily as follows: day 1, 0730 and 1330; day 2, 0900 and 1500; day 3, 1030 and 1630 and day 4, 1200 and 1800. Individual samples consisted of approximately 700 mL duodenal chyme and 200 g (wet basis) of fecal material. Samples from each steer were composited within period for analysis. During the final day of each collection period, ruminal samples were obtained from each steer 4 h after feeding via the ruminal cannula. Ruminal fluid pH was determined on fresh samples. Samples were strained through 4 layers of cheese cloth. Two milliliter of freshly prepared 25% (w/v) meta-phosphoric acid was added to 8 mL of strained ruminal fluid. Samples were then centrifuged (17,000× g for 10 min) and supernatant fluid stored at -20°C for VFA analysis. 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). Samples were subjected to all or part of the following analysis: DM (oven drying at 105°C until no further weight loss); ash, Kjeldahl N, ammonia N (AOAC, 1984); purines (Zinn and Owens, 1986); VFA concentrations of ruminal fluid (gas chromatography; Zinn, 1988); chromic oxide (Hill and Anderson, 1958); NDF (Goering and Van Soest, 1970; corrected for neutral detergent insoluble ash) and starch (Zinn, 1990a). Microbial Organic Matter (MOM) and N (MN) leaving the abomasum were calculated using purines as a microbial marker (Zinn and Owens, 1986). Organic Matter Fermented in the rumen (OMF) 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 leaving the abomasum minus ammonia-N and MN and, thus, includes any endogenous contributions. Methane production was calculated based on the theoretical fermentation balance for observed molar distribution of VFA and OM fermented in the rumen (Wolin, 1960). The trial was analyzed as a 4×4 Latin square experiment (Hicks, 1973). Treatment effects were tested for the following orthogonal components: DRC vs TRC, T-5 min-SFC vs 25 min-SFC and rolled corn vs steam-flaked corn.

Trial 2: Effects of tempering and steaming rate of steam-flaked corn on performance of feedlot cattle: Eighty crossbred heifers with an average initial weight of 248 kg were used in a 105 day randomized complete block design experiment, to evaluate the effects of two delivery rates of steam to the steam chest (steam-line injection pressure of 1.2 vs 3.9 kg L^{-1}) with and without tempering in a 2×2 factorial arrangement on growth-performance. The heifers were blocked by weight and randomly assigned within weight groups to 16 pens. Four treatments were used: no tempering and 117 kPa of steam pressure (measured 2 m in line from the boiler toward the steam chest, 90 cm from the steam chest splitter valve; Reotemp, San Diego, CA; NT117); no tempering and 379 kPa steam pressure (NT379); tempering and 117 kPa steam pressure (T117) and tempering and 379 kPa steam pressure (T379). The boiler pressure was set at 483 kPa. Steam temperature, just prior to entering the steam chest, averaged 145°C. Steam-flaked corn was prepared as follows. A steam chest situated directly above the rollers (same as in Trial 1) was filled to capacity (441 kg) with corn. Corn was steamed according to designated treatment at atmospheric pressure for approximately 20 min. The first approximately 441 kg of SF corn was allowed to pass from the rollers before material was collected for use in the trial. Tempering consisted of spraying 0.075 L kg^{-1} water mixed with 181 mg kg^{-1} of a tempering agent (Sar Temp®; Sar Tec, Anoka, MN) on the corn 30 min before applying steam. For all processing treatments corn was flaked to a density of 0.31 kg L^{-1} (24 lbs/bushel), as measured directly beneath the rolls. Steam-flaked corn was allowed to air dayry for 2 day before it was incorporated into the diets, which were elaborated at weekly intervals and stored in plywood boxes located in front of each pen. Pens were 50 m^2 with 33 m^2 overhead shade, automatic waters and 4.3 m fence-line feed bunks. Composition of the experimental diets is shown in Table 1. The cattle were allowed ad libitum access to feed. Fresh feed was provided twice daily. Fresh water was available all times. Heifers were

Table 1: Ingredients and composition of experimental diets fed to steers (trials 2 and 3)[a]

Item	Corn processing[b] NT117	NT379	T117	T379
Ingredient composition (%) (DM basis)				
Alfalfa hay	3.83	3.83	3.83	3.83
Sudan grass	7.67	7.67	7.6.7	7.67
Steam flaked corn	75.92	75.92	75.92	75.92
Yellow grease	2.64	2.64	2.64	2.64
Cane molasses	7.04	7.04	7.04	7.04
Limestone	1.31	1.31	1.31	1.31
Urea	0.97	0.97	0.97	0.97
Magnesium oxide	0.18	0.18	0.18	0.18
Trace mineral salt[c]	0.44	0.44	0.44	0.44
Laidlomycin, g/ton	46.00	46.00	46.00	46.00
Nutrient composition (DM basis)[d]				
NE, Mcal kg^{-1}				
Maintenance	2.23	2.23	2.23	2.23
Gain	1.56	1.56	1.56	1.56
Crude protein (%)	12.28	12.28	12.28	12.28
Ether extract (%)	6.49	6.49	6.49	6.49
ADF (%)	6.64	6.64	6.64	6.64
Calcium (%)	0.71	0.71	0.71	0.71
Phosphorus (%)	0.28	0.28	0.28	0.28
Potassium (%)	0.77	0.77	0.77	0.77
Magnesium (%)	0.30	0.30	0.30	0.30
Sulfur (%)	0.16	0.16	0.16	0.16

[a]Chromic oxide added at 0.4% as digesta marker in trial 3. [b]Corn processing consisted of: No Tempering (NT), Tempering (T) and two steam pressures of 17 and 55 psi measured 1 m from the boiler prior to rolling. [c]Trace mineral salt contained (%): $CoSO_4$, 0.068; $CuSO_4$, 1.04; $FeSO_4$, 3.57; ZnO, 1.24; $MnSO_4$, 1.07; KI, 0.052; and NaCl, 92.96. [d]Based on tabular values for individual feed ingredients (NRC, 1984) with the exception of supplemental fat, which was assigned NEm and NEg values of 6.03 and 4.79, respectively

weighed at 35 day intervals and were implanted with Synovex-H® (Fort Dodge Animal Health, Fort Dodge, IA) upon initiation of the trial and reimplanted with Revalor-H two months later. Energy Gain (EG) was calculated by the equation:

$$EG = ADG^{1.119}.0686W^{0.75}$$

Where,
EG = The daily energy deposited (Mcal day^{-1}).
W = The mean shrunk body weight (kg; NRC 1984).

Maintenance Energy (EM) was calculated by the equation:

$$EM = .077W^{0.75}$$ (Lofgreen and Garret, 1968)

The NE_m and NE_g value of the diets were obtained by means of the quadratic equation:

$$\left(x = \frac{-b - \sqrt{b^2 - 4ac}}{2c}\right)$$

Where,
a = -0.41EM
b = 0.877EM + 0.41DMI + EG
c = -0.877DMI
Ne_g = $0.877NE_m$-0.41

This trial was analyzed as a randomized complete block design experiment (Hicks, 1973), using pens as the experimental unit. Treatment effects were tested by means of the following orthogonal polynomials: NT117 vs NT379, T117 vs T379 and No Tempering (NT) vs Tempering (T).

Trial 3: Effects of tempering and steaming rate of steam-flaked corn on characteristics of digestion in feedlot cattle diets: Four Holstein steers with cannulas in the rumen and proximal duodenum (Zinn and Plascencia, 1993) were used in a 4×4 Latin square experiment to evaluate treatment (same as in Trial 2) effects on characteristics of ruminal and total tract digestion. Composition of the experimental diets was the same as in Trial 2, with the inclusion of 0.4% chromic oxide as a digest marker. Diets were fed in equal proportions at 0800 and 2000 daily. Individual feed intake was restricted to an average of 3.76 kg day^{-1} (DM basis). Experimental periods, collection, samples preparation and analysis were similar as Trial 1. This trial was analyzed as a 4×4 Latin square experiment (Hicks, 1973). Treatment effects were tested by means of orthogonal polynomials, as indicated for Trial 2.

Trial 4: Effects of tempering and steaming pressure on feeding value of steam-flaked corn in finishing diets for feedlot cattle: Ninety-six crossbred steer calves with an average initial weight of 347 kg were used in a 56 day randomized complete block design experiment, to evaluate the interaction of steam reduction (419 vs 335 kPa pressure along a 6.35 cm diam steam line, measured 90 cm proximal to steam chest splitter valves) and tempering in a 2×2 factorial arrangement on growth-performance and feeding value of SFC for feedlot cattle. The steer were blocked by weight and randomly assigned within weight groups to 16 pens. The treatments were: no tempering and 419 kPa along a 6.35 diam steam line, measured 90 cm proximal to steam chest splitter valves. (NT419); no tempering and 335 kPa of steam (NT335); tempering and 419 kPa of steam (T419) and tempering and 335 kPa of steam (T335). A chest situated directly above the rollers (46×61 cm corrugated, Memco Mill Rolls, Mill Engineering and Machinery Co., Oklahoma, CA) was filled to capacity (441 kg) with corn. Corn treatments were steamed for approximately 30 min before flaking to a density of

Table 2: Ingredients and composition of experimental diets fed to steers (trials 4 and 5)[a]

Item	Corn processing[b]			
	NT419	T419	NT335	T335
Ingredient composition (%) (DM basis)				
Alfalfa hay	3.83	3.83	3.83	3.83
Sudan grass	7.67	7.67	7.67	7.67
Steam flaked corn	75.92	75.92	75.92	75.92
Yellow grease	2.64	2.64	2.64	2.64
Cane molasses	7.04	7.04	7.04	7.04
Limestone	1.31	1.31	1.31	1.31
Urea	0.97	0.97	0.97	0.97
Magnesium oxide	0.18	0.18	0.18	0.18
Trace mineral salt[c]	0.44	0.44	0.44	0.44
Laidlomycin, g/ton	46.00	46.00	46.00	46.00
Nutrient composition (DM basis)[d]				
NE, Mcal kg^{-1}				
Maintenance	2.23	2.23	2.23	2.23
Gain	1.56	1.56	1.56	1.56
Crude protein (%)	12.28	12.28	12.28	12.28
Ether extract (%)	6.49	6.49	6.49	6.49
ADF (%)	6.64	6.64	6.64	6.64
Calcium (%)	0.71	0.71	0.71	0.71
Phosphorus (%)	0.28	0.28	0.28	0.28
Potassium (%)	0.77	0.77	0.77	0.77
Magnesium (%)	0.30	0.30	0.30	0.30
Sulfur (%)	0.16	0.16	0.16	0.16

[a]Chromic oxide added at 0.4% as digesta marker in trial 5. [b]Corn processing consisted of: No Tempering (NT), Tempering (T) and two steam pressures of 419 and 335 kPa along a 6.35cm diam steam line, measured 90cm proximal to steam chest splitter valves. [c]Trace mineral salt contained (%): $CoSO_4$, 0.068; $CuSO_4$, 1.04; $FeSO_4$ 3.57; ZnO, 1.24; $MnSO_4$, 1.07; KI, 0.052 and NaCl, 92.96. [d]Based on tabular values for individual feed ingredients (NRC, 1984) with the exception of supplemental fat, which was assigned NEm and NEg values of 6.03 and 4.79, respectively

0.31 kg L^{-1}. The first approximately 441 kg of SF corn was allowed to pass from the rollers before material was collected for use in the trial. Tempering consisted 60 min exposure to 40 g kg^{-1} water plus 0.275 mg kg^{-1} of Sartemp on the corn 30 min before applying steam. Steam-flaked corn was allowed to air-dry for 2 day before it was incorporated into the diets, which were elaborated at weekly intervals and stored in plywood boxes located in front of each pen. Pens were 50 m^2 with 33 m^2 overhead shade, automatic waters and 4.3 m fence-line feed bunks. Composition of the experimental diets is shown in Table 2. The cattle were fed ad libitum twice daily and fresh water was available all times. Energy Gain (EG), NE_m and NE_g values were obtained as was described in trial 2. Treatment effects were tested by means of the following orthogonal polynomials: NT419 vs NT335, T419 vs T335 and No Tempering (NT) vs Tempering (T).

Trial 5: Effects of tempering and steaming pressure of steam-flaked corn on characteristics of digestion in feedlot cattle diets: Four Holstein steer with ruminal and duodenal cannulas were used in a 4×4 Latin square design to evaluate the treatment (same as in Trial 4) effects on digestive function. Composition of the experimental diets was the same as in Trial 4, with the inclusion of 0.4% chromic oxide as a digest marker. Diets were fed in equal proportions at 0800 and 2000 daily. Dry matter intake was limited to 2% of BW. Experimental periods, collection, sample preparation and analysis were similar to trial 1. This trial was analyzed as a 4×4 Latin square (Hicks, 1973). Treatment effects were tested by means of orthogonal polynomials, as in Trial 4.

RESULTS AND DISCUSSION

Effects of corn processing on characteristics of ruminal and total tract digestion are shown in Table 3. There were no treatment effects ($p>0.10$) on ruminal digestion of OM, ruminal degradation of feed N and ruminal microbial efficiency. Consistent with Zinn *et al.* (1998) and Zinn *et al.* (1995), SF did not affect ruminal degradation of feed N. However, Zinn *et al.* (1998) reported that ruminal digestion of OM and starch were greater for SFC than for DR or TRC. There was a tendency ($p = 0.19$) for ruminal NDF digestion to be lower (3.8%) for 25 min-SFC than for T-5 min-SFC. Consistent with previous studies (Zinn and Plascencia, 1996; Barajas and Zinn, 1998; Corona *et al.*, 2006) ruminal starch digestion was greater (14.1%, $p<0.05$) for steam-flaked corn treatments than for rolled corn treatments (75.8 vs 66.4%, respectively). Consistent with Zinn *et al.* (1998) and Zinn *et al.* (1995), ruminal N efficiency (non-ammonia N entering the small intestine/N intake) tended to be greater ($p = 0.13$) for steam flaked corn treatments than for rolled corn treatments. Consistent with Zinn (1988) and Zinn *et al.* (1998), post ruminal and total tract digestion of OM, starch and N were greater ($p<0.05$) for steam-flaked corn treatments than for rolled corn treatments. Ruminal, postruminal and total tract digestion of OM, starch and N were similar ($p>0.20$) for T-5 min-SFC and T-25 min-SFC treatments. Consistent with previous studies (Zinn *et al.*, 1995; Barajas and Zinn, 1998; Corona *et al.*, 2006), SF increased ($p<0.05$) postruminal digestion of OM (23.3%), starch (10.4%), N(54.6%) and total tract digestion of OM (11.9%), starch (9.7%) and N (12.1%). The values for total tract starch digestion averaged 96.6 and 86.15%, respectively for SFC and DRC. The value for DRC is consistent with Corona *et al.* (2006), but is lower than the average value reported by Owens and Zinn (2005). Also, the value for SFC in this trial was less (2.4%) than the values observed previously (Zinn *et al.*, 2002; Owens and Zinn, 2005; Corona *et al.*, 2006).

Influences of corn processing on ruminal pH, VFA and estimated methane production are shown in Table 4. Ruminal pH was lower (4.8%, $p<0.05$) for steam-flaked corn treatments than for rolled corn treatments. Ruminal

Table 3: Influence of corn processing on characteristics of ruminal and total tract digestion (Trial 1)

	Corn prossesing[a]				
Item	DRC	TRC	T-5 min-SFC	25 min-SFC	SD
Intake (g day^{-1})					
DM	5591.0	5601.0	5656.0	5640.0	
OM	5249.0	5270.0	5319.0	5318.0	
NDF	871.0	839.0	856.0	851.0	
N	99.5	99.7	100.0	98.7	
Starch	2488.0	2526.0	2608.0	2600.0	
Ruminal digestion (%)					
OM	55.63	50.64	59.94	57.68	7.780
NDF	53.02	47.05	53.78	41.08	12.500
Feed-N	61.24	59.01	56.90	57.68	5.260
Starch	70.01[bc]	62.74[b]	75.92[c]	75.71[c]	6.500
Microbial efficiency[d]	22.49	25.36	21.08	22.22	3.550
N efficiency[e]	1.04	1.07	1.10	1.11	0.064
Post ruminal digestion (%) duodenal					
OM	47.40[b]	51.68[bc]	58.83[cf]	63.31[f]	6.09
N	65.02[b]	65.52[b]	71.61[c]	72.48[c]	1.68
Starch	49.99[b]	60.43[b]	81.47[c]	89.18[c]	13.5
Total tract digestion (%)					
OM	70.82[b]	70.68[b]	78.44[c]	79.87[c]	2.17
NDF	46.36	43.16	51.25	48.38	7.02
N	62.58[b]	61.87[b]	67.89[c]	68.64[c]	2.13
Starch	86.26[b]	86.04[b]	95.61[c]	97.49[c]	2.45

[1]Corn processing was: DRC = Dry Rolled Corn (without steam), TRC = tempered corn that is rolled without steam, T-5min-SFC = tempered corn that is steamed for approximately 5 min and flaked to a density of 0.36 kg L^{-1} and SFC = corn that is steamed for 25 min before flaking to a density of 0.31 kg L^{-1}. [bcf]Means within a row with different superscripts differ ($p<0.05$). [d] = Microbial N, g kg^{-1} OM fermented. [e] = Nonammonia N leaving the abomasum/N intake

Table 4: Effects of corn processing on ruminal pH, VFA and estimated methane production (Trial 1)

	Corn processing[a]				
Item	DRC	TRC	T-5 min-SFC	25 min-SFC	SD
Ruminal pH	6.30[b]	6.30[b]	5.90[c]	6.10[bc]	0.20
Ruminal VFA, mol 100 mol^{-1}					
Acetate	62.20[b]	62.40[b]	52.10[c]	58.70[bc]	7.10
Propionate	23.80[bc]	22.60[b]	34.60[c]	30.60[c]	6.10
Butyrate	14.00	15.00	13.30	10.70	5.20
Ratio: acetate/ propionate	2.72[bc]	3.10[b]	1.70[c]	1.97[c]	0.77
Methane production[f]	0.56[b]	0.58[b]	0.43[c]	0.49[bc]	0.08

[a]Corn processing was: DRC = Dry Rolled Corn (without steam), TRC = tempered corn that is rolled without steam, T-5min-SFC = tempered corn that is steamed for approximately 5 min and flaked to a density of 0.36 kg L^{-1} and SFC = corn that is steamed for 25 min before flaking to a density of 0.31 kg L^{-1}. [bc]Means within a row with different superscripts differ ($p<0.05$). [f]Methane, mol/mol glucose equivalent fermented (Wolin, 1960)

acetate: propionate molar ratios and estimated methane production were also lower for steam-flaked corn treatments than for rolled corn treatments. Decreased ruminal pH (Zinn *et al*., 1995; Corona *et al*., 2006), increased ruminal, postruminal and total tract digestion of starch and decreased estimated methane energy loss are characteristic responses to steam flaking corn (Zinn, 1987, 1988; Zinn *et al*., 1995, 1998; Corona *et al*., 2006). The similarities between T-5min-SFC and 25min-SFC with respect to site and extent of starch digestion and VFA molar proportions are promising evidence that pretempering corn prior to steam flaking may reduce steam requirements to obtain optimal utilization of corn.

Research evaluating the minimal steaming time necessary to produce optimal flake is limited (Zinn *et al*., 2002). Zinn (1990b) demonstrated that steaming for more than 30 min did not enhance starch digestibility (already over 99%) for corn flaked to a density of 0.31 kg L^{-1}. The small (2.0%) numerical advantage of 25 min-SFC over that of T-5 min-SFC may reflect the higher (0.31 vs 0.36 kg L^{-1}) flake density of the latter (Zinn, 1990a).

Treatment effects on growth performance of finishing heifers are shown in Table 5. There were no treatment effects ($p>0.20$) on ADG, DMI, gain efficiency, or dietary NE. These results indicate that it is feasible to reduce the rate of steam flow to the steam chest without affecting the feeding value of SFC. Likewise, Zinn *et al*. (2000) did not observe an effect of tempering before flaking on growth performance or the NE value of SFC. Zinn (1990b) observed that steaming, alone (without tempering), of corn for approximately 30 min at atmospheric pressure will increase it's moisture content by 3.5-4.0% units; sufficient to allow for an optimal flake. In the present study, dramatically reducing steaming rate nevertheless did not reduce moisture uptake by the corn, nor the efficiency of the flaking process, as measure in terms of dietary NE.

The relationship between tempering and steaming rate of flaked corn on characteristics of digestion of finishing diets fed to steers is shown in Table 6. Tempering did not affect ($p>0.10$) ruminal digestion of nutrients or the microbial and N efficiencies. Tempering increased ($p<0.05$) post ruminal digestion of OM (3.4%) and starch (3.8%) and total tract digestion of OM (1.4%), starch (0.5%) and N (3%). The improvement in total tract OM digestion was not reflected in enhanced growth performance and dietary NE (Table 5; Trial 2), perhaps due to the small numerical magnitude of the difference. Zinn *et al*. (1998) did not observe effects of tempering on ruminal and total tract digestion of OM.

Tempering did not affect microbial N efficiency. In as much as sarsaponin is a principal active ingredient in the surfactant used to temper corn, increased ruminal microbial efficiency was plausible (Zinn *et al*., 1998; Zinn, 1988).

There were no treatment effects ($p>0.20$; Table 7) on ADG (1.24 kg day^{-1}), DM conversion (5.60 kg DM kg^{-1} ADG) and dietary NE for maintenance and gain (2.24 and 1.55 Mcal kg^{-1}, respectively). Close agreement between observed and expected dietary NE indicates that across treatments the NE values for SFC were consistent with tabular values (2.38 and 1.68 Mcal kg^{-1}, respectively; NRC, 1996).

Table 5: Effect of tempering corn and steam line pressure before flaking on growth performance of feedlot heifers fed a steam-flaked corn-based finishing diet (Trial 2)

	Corn processing[a]				Main effects				
Item	NT 17	NT 55	T 17	T 55	NT	T	17	55	SEM
Live weight, kg[b]									
Initial	251.00	245.00	248.00	248.00	248.00	248.00	250.00	246.00	1.30
Final	480.00	467.00	473.00	462.00	473.00	467.00	176.00	464.00	9.00
DM intake, kg day^{-1}	6.77	6.52	6.72	6.41	6.64	6.56	6.74	6.46	0.20
ADG, kg day^{-1}	1.31	1.27	1.28	1.22	1.29	1.25	1.29	1.25	0.05
ADG/DMI	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.01
Dietary NE, Mcal kg^{-1}									
Maintenance	2.39	2.38	2.36	2.36	2.38	2.36	2.37	2.37	0.05
Gain	1.69	1.68	1.65	1.66	1.68	1.66	1.67	1.67	0.04
Observed/expected NE									
Maintenance	1.07	1.07	1.06	1.06	1.07	1.06	1.06	1.06	0.02
Gain	1.08	1.08	1.06	1.07	1.08	1.06	1.07	1.07	0.03

[a]Corn processing consisted of: No Tempering (NT), Tempering (T) and two steam pressures of 17 and 55 psi measured 1 m from the boiler prior to rolling. [b]Initial and final live weights were reduced 4% to account for rumen fill

Table 6: Relationship between tempering and level of steam of flaked corn on characteristics of digestion of finishing diets fed to steers (Trial 3)

	Corn processing[a]				Main effects				
Item	NT17	NT55	T17	T55	NT	T	17	55	SEM
Intake, g day^{-1}									
DM	7609.00	7540.00	7419.00	7493.00	7574.00	7456.00	7514.00	7516.00	
OM	7178.00	7138.00	7016.00	7064.00	7158.00	7040.00	7097.00	7101.00	
NDF	951.00	965.00	965.00	922.00	958.00	943.00	958.00	943.00	
N	136	135.00	136.00	136.00	136.00	136.00	136.00	135.00	
Starch	3660.00	3747.00	3568.00	3604.00	3704.00	3586.00	3614.00	3676.00	
Ruminal digestion (%)									
OM	64.42	66.59	66.56	63.39	65.50	64.97	65.49	65.00	0.010
NDF	20.40	24.09	31.99	22.81	22.24	27.40	26.19	23.45	0.060
Fed-N	65.36	67.23	65.72	68.96	66.30	67.34	65.54	68.10	0.020
Starch[e]	81.56	84.16	82.29	79.17	82.86	80.73	81.93	81.66	0.010
Microbial efficiency[b]	21.90	20.39	17.58	22.28	21.15	19.93	19.74	21.34	1.420
N efficiency[c]	1.09	1.05	0.94	1.04	1.07	0.99	1.02	1.04	0.060
Post ruminal digestion (%) duodenal									
Om[d]	64.47	65.90	67.92	66.95	65.19	67.43	66.20	66.42	0.010
NDF	30.59	24.28	29.25	23.26	27.43	26.26	29.92	23.77	0.050
N	74.97	75.65	75.75	75.73	75.31	75.74	75.36	75.69	0.01
Starch[ef]	86.84	90.79	90.02	92.77	88.82	91.39	88.43	91.78	0.010
Total tract digestion (%)									
Om[d]	82.39	84.04	85.5	83.25	83.21	84.40	83.97	83.65	0.010
NDF[g]	44.93	45.46	51.88	42.09	45.19	46.99	48.40	43.78	0.020
N[d]	71.89	73.67	76.26	73.67	72.78	74.96	74.07	73.67	0.010
Starch[f]	97.67	98.54	98.33	98.49	98.11	98.41	98.00	98.52	0.002

[a]Corn processing consisted of: No Tempering (NT), Tempering (T) and two steam pressures of 17 and 55 psi measured 1 m from the boiler prior to rolling. [b]Microbial N, g kg^{-1} OM fermented. [c]Nonammonia N leaving the abomasum/N intake. [d]Main effect of no tempering vs tempering ($p<0.05$). [e]Main effect of no tempering vs tempering ($p<0.10$). [f]Main effect of steam 17 vs 55 ($p<0.05$). [g]Main effect of steam 17 vs 55 ($p<0.10$)

Consistent with Trial 2 and previous studies (Zinn, 1990b; Zinn *et al.*, 2000) reduction of steam pressure (419 vs 335 kPa pressure along a 6.35 cm diam steam line, measured 90 cm proximal to steam chest splitter valves) and tempering did not negatively affect growth performance of cattle or NE value of corn.

The relationships between tempering and level of steam line pressure before flaking on characteristics of digestion are shown in Table 8. The percentage of corn starch that was reactive to amylglucosidase (a measure of starch solubility) was similar across SFC treatments, averaging 22%. Consistent with Trial 2 and Zinn *et al.* (1998), ruminal digestion of OM averaged 65.0% and was not affected ($p>0.20$) by treatments. Tempering increased (4.9%, $p<0.05$) ruminal starch digestion. However, ruminal starch digestion was not influenced by steam line pressure reduction (80.7 vs 80.4%, $p>0.20$). Consistent with Trial 3, tempering did not affect ($p>0.20$) microbial N efficiency. Likewise, there were no treatment effects ($p>0.20$) on total tract digestion of OM and starch, averaging 82.8 and 97.7%, respectively.

Table 7: Effect of tempering and level of steam pressure of flaked corn on growth performance of feedlot steers (trial 4)

	Corn processing [a]				Main effects				
Item	NT 419	T 419	NT 335	T 335	419	335	NT	T	SEM
Live weight, kg[b]									
Initial	346.00	348.00	347.00	347.00	347.00	347.00	346.00	348.00	1.50
Final	413.00	423.00	413.00	415.00	418.00	414.00	413.00	419.00	6.20
DM intake, kg day^{-1}	6.66	7.20	6.71	6.93	6.93	6.82	6.69	7.06	0.26
ADG, kg day^{-1}	1.21	1.34	1.19	1.23	1.27	1.21	1.20	1.28	0.09
DMI/ADG	5.63	5.41	5.67	5.69	5.52	5.68	5.65	5.55	0.25
Dietary NE, Mcal kg^{-1}									
Maintenance	2.26	2.26	2.24	2.21	2.26	2.22	2.25	2.23	0.04
Gain	1.57	1.57	1.55	1.53	1.57	1.54	1.56	1.55	0.04
Observed/expected NE									
Maintenance	1.01	1.01	1.00	0.99	1.01	0.99	1.03	1.03	0.02
Gain	1.02	1.01	1.00	0.99	1.02	0.99	1.01	1.00	0.02

[a]Corn processing consisted of: No tempering (NT), tempering (T) and two steam pressures of 419 and 335 kPa along a 6.35 cm diameter steam line, measured 90cm proximal to steam chest splitter valves, [b]Initial and final live weights were reduced 4% to account for rumen fill

Table 8: Relationship between tempering and level of steam pressure of flaked corn on characteristics of digestion of finishing diets fed to steers (Trial 5)

	Corn processing[a]				Main effects				
Item	NT419	T419	NT335	T335	419	335	NT	T	SEM
Intake, g day^{-1}									
DM	4154.00	4198.00	4172.00	4190.00	4176.00	4181.00	4163.00	4194.00	
OM	3948.00	3973.00	3909.00	3972.00	3961.00	3941.00	3928.00	3973.00	
N	70.62	68.42	69.66	70.82	69.52	70.24	70.14	69.62	
Starch	2098.00	2158.00	2107.00	2187.00	2128.00	2147.00	2102.00	2172.00	
Ruminal digestion (%)									
OM	64.87	66.70	63.56	64.92	65.78	64.24	64.21	65.81	1.60
Fed-N	58.95	60.65	63.94	59.47	59.80	60.06	61.44	60.06	1.58
Starch[b]	78.71	82.69	78.52	82.19	80.70	80.35	78.61	82.44	1.27
Microbial efficiency[c]	21.07	20.59	21.81	21.49	20.83	21.65	21.44	21.04	0.68
N efficiency[d]	1.17	1.19	1.14	1.19	1.18	1.16	1.15	1.19	0.03
Post ruminal digestion (%) duodenal									
OM	66.43	61.57	64.89	64.46	64.00	64.67	65.66	63.01	2.21
N	74.38	72.59	73.39	74.78	73.48	74.08	73.89	73.68	1.05
Starch	89.19	88.13	87.76	86.72	88.66	87.24	88.47	87.42	3.27
Total tract digestion (%)									
DM	81.83	79.84	80.03	80.34	80.83	80.19	80.93	80.09	0.67
OM	83.97	82.14	82.35	82.62	83.06	82.49	83.16	82.38	0.68
N	69.05	66.38	68.84	69.09	67.71	68.96	68.94	67.73	0.92
Starch	97.72	98.12	97.25	97.65	97.92	97.44	97.49	97.88	0.47

[a]Corn processing consisted of: No Tempering (NT), Tempering (T) and two steam pressures of 419 and 335 kPa measured 1 m from the boiler prior to rolling. [b]Main effect of no tempering vs tempering ($p<0.05$). [c]Microbial N, g kg^{-1} OM fermented. [d]Nonammonia N leaving the abomasum/N intake

CONCLUSION

Similarities between T-5 min-SFC and 25 min-SFC with respect to site and extent of starch digestion and VFA molar proportions are promising evidence that pretempering corn prior to steam flaking may reduce the minimal steam requirements to obtain optimal utilization of corn. Provided that the lower quarter of the steam chest is maintained at temperatures greater than 100°C, reducing steam application by as much as 20% will not detrimentally affect the feeding value of SFC.

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