Journal of Animal and Veterinary Advances 6 (1): 118-122, 2007
© Medwell Journals, 2007

Influence of Cracked, Coarse Grind, or Fine Grind of Corn on Digestion and Rumen Function in Steers Fed a 73% Corn-Based Diet

[1]Alejandro Plascencia and [2]A.V. Jose Maria
[1]Instituto de Investigaciones en Ciencias Veterinarias-UABC, Mexicali, México
Aguayo # Frace. Vistaherrmosa CP 21240. Mexicali, Baja California, Mexico

Abstract: Four Holstein steers (142±9.3 kg) with cannulas in the rumen and p>roximal duodenum were used in a 4×4 Latin square experiment to evaluate the influence of corn processing on digestive function. Four dietary treatments were compared: 1) SFC (density = 0.31 kg L^{-1}); 2) coarsely-ground corn (DRC-CG, density = 0.55 kg L^{-1}); 3) Medium-coarsely Ground-corn (DRC-MG, density = 0.50 kg L^{-1}) and 4) Fine-ground corn (DRC-FG, density = 0.45 kg L^{-1}).The basal diet contained 73.25 corn and 9.8 % forage. Method of corn processing had no effect ($p>0.10$) on ruminal pH, VFA or methane production. There were no treatment effects ($p>0.10$) on ruminal digestion of feed N and ruminal microbial efficiency. Ruminal and total tract digestion of ADF was not affected ($p>0.10$) by corn processing. Ruminal digestibility of OM and starch was greater (12.6 and 14%, respectively; $p>0.10$) for SFC than for DRC-CG, DRC-MG and DRC-FG. Total-tract digestibilities of OM, starch, N and DE were greater (6.1, 3.9, 8.4 and 7.3% respectively, $p>0.10$) for SFC than for DRC treatments. Total tract digestibility of starch tended to increase (linear component, $p>0.10$) with degree of dry processing, although total tract digestibility of OM and GE was not improved ($p>0.10$). Given that the DE value of SFC was 4.10 Mcal kg^{-1}, the DE values for DRC-CG, DRC-MG and DRC-FG were 3.88, 3.71 and 3.60 Mcal kg^{-1}, respectively. It is concluded that the feeding value of dry-processed corn is not enhanced by reducing the particle size of the kernels beyond to that obtained following coarse rolling.

Key words: Corn, processing, digestion, cattle, ruminal, tract digestion

INTRODUCTION

The potential for improved starch utilization and energy value of corn as a result of processing is well documented (Owens *et al*., 1997; Zinn *et al*., 2002). In a summary of trials evaluating processing effects on the feeding value of corn, (Huntington, 1997) observed that the average digestibility coefficients of starch in Steam-Flaked Corn (SFC) were: ruminal, 84.8%±4.1; postruminal, 14.1%±3.7 and total tract, 98.2%±0.8. Corresponding values for Dry Rolled Corn (DRC) were: 76.2%±7.9, 16.2%±6.7 and 92.2%±3.0, respectively. The variation in site and extent of digestion of starch for DRC was greater then that of SFC. This variation in digestibility may be due in part to differences in degree of processing (fineness of grind) of the DRC. The objective of this study was to investigate the influence of the degree of processing of DRC on the site and extent of starch digestion in steers fed a corn-based finishing diet.

MATERIALS AND METHODS

Four Holstein steers (142±9.3 kg) with cannulas in the rumen and proximal duodenum (6 cm from the pyloric sphincter) were used in a 4×4 Latin square experiment. Steers were maintained in slotted-floor pens (6.2 m^{-}) with ad libitum access to water. Dietary treatments were:

- Steam-flaked corn (SFC, density = 0.31 kg L^{-1})
- Coarsely-ground corn (DRC-CG, density = 0.55 kg L^{-1})
- Medium-coarsely ground-corn (DRC-MG, density = 0.50 kg L^{-1})
- Fine-Ground corn (DRC-FG, density = 0.45 kg L^{-1}).

Experimental diets are shown in Table 1. The DR corn treatments were prepared by passing corn through rollers that had been adjusted so that kernels were broken to obtain the desired density. The SFC was prepared as follows: A chest situated directly above the rollers (46×61cm, corrugated) was filled to capacity (441 kg) with 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 441 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

Corresponding Author: A.V. Jose Maria, Aguayo # Frace. Vistaherrmosa CP 21240. Mexicali, Baja California, Mexico

density (0.31 kg L^{-1}). Retention time of grain in steam chamber was approximately 18 min. The SFC was allowed to air-dry (5 d) before use in diet preparation. The experiment was carried out at the Ruminant Digestion and Metabolism Test Unit of the Veterinary Science Research Institute of the Autonomous University of Baja California, located in Mexicali City, in the state of Baja California, Mexico. Dry matter intake was restricted to 3.13 kg d^{-1} (2.2% of BW). Diets were fed at 0800 and 2000 daily. 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; d 2, 0900 and 1500; d 3, 1050 and 1650; and d 4, 1200 and 1800. Individual samples consisted of approximately 500 mL 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, ruminal samples were obtained from each steer 4 h postprandial via the ruminal cannula. Ruminal fluid pH was determined on fresh samples. Samples were strained through 4 layers of cheese cloth. Two mL 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 isolationof 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); Gross energy (GE) (Plascencia *et al.*, 2002); VFA concentrations of ruminal fluid (gas chromatography (Zinn and Plascencia, 1993) chromic oxide (Hill and Anderson, 1958) ADF (Goering and Van, 1970) and starch (Zinn, 1990). 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 statistical model was: $Y_{ijkl} = F+C_i+A_j+P_k+E_{ijk}$, where Y_{ijk} is the response variable, C_i is the corn processing effect, A_j is the animal effect, P_k is the period effect and E_{ijk} is the residual error. Treatment effects were tested for the following orthogonal components:

- SFC vs DRC
- Linear effect of density of DRC
- Quadratic effect of density of DRC (Hicks, 1973).

Table 1: Composition of experimental diets fed to steers (DM basis)

	Treatments[a]	
Ingredient	SFC	DRC
Alfafa hay	3.90	3.90
Sundagrass hay	5.80	5.80
Steam-flaked corn	73.40	--
Dry-rolled corn	--	73.25
Cane molasses	7.30	7.30
Yellow grease	3.50	3.50
Cottonseed meal	1.85	1.95
Urea	0.97	0.97
TM salt[b]	0.35	0.35
Magnesium oxide	0.13	0.13
Sodium bicarbonate	0.85	0.90
Ammonium sulphate	0.15	0.15
Phosphate rock	1.40	1.40
Chromic oxide	0.40	0.40
Nutrient cmpositoin		
NE. Mcal kg^{-1}		
Maintenence	2.23	2.13
Gain	1.57	1.47
Crude protien, %	12.51	12.73
ADF, %	6.11	6.52
Lipid, %	6.90	6.90
Calcium, %	0.70	0.70
Phosphorus, %	0.47	0.47

[a]SFC = Steam Flaked Corn, DRC = Dry Rolled Corn. [b]Trace mineral sal contained: $CoSO_4$, .068%; $CuSO_4$, 1.04%; $FeSO_4$, 3.57%; ZnO, 1.24%; $MnSO_4$, 1.07%; KI, .052%; and NaCl 92.96%. [c]Based on tabular values for individual feed ingredients (NRC, 1996)

RESULTS AND DISCUSSION

The influence of processing on characteristics of particle size and bulk density of corn are shown in Table 2. As expected, increasing the intensity of grinding, decreased the integrity of the kernel during dry rolling. Thus, the amount of particles less than 4 mm (as percentage of the total) were 67, 52 and 40% for DRC-FG, DRC-MG and DRC-CG respectively. Similar to previous

Table 2: Treatment effects on average particle size distribution and bulk density of corn

		Dry-rolled corn[a]		
Sieve, mm	SFC	FG	MG	CG
16.00	0.0	0.0	0.0	0.0
8.00	28.6	2.2	3.0	7.0
4.00	34.9	30.7	51.2	53.1
2.00	20.2	43.7	33.4	33.2
1.00	8.5	13.1	6.3	2.0
0.50	3.5	4.5	2.6	1.9
0.25	2.6	2.7	1.4	1.1
0.00	1.7	3.1	2.1	1.7
Total	100	100	100	100
Bulk desnity kg L^{-1}	0.31	0.45	0.50	0.55

[a]C = coarse grind (density = 0.55), M = medium coarse grind (density = 0.50) and F = fine grind (density = 0.45)

Table 3: Treatment effects on ruminal pH, VFA molar proportion and methane production 4 h after feeding

		Dry-rolled corn[a]			
Item	SFC	FG	MG	CG	SEM
Ruminal pH	5.86	5.89	5.83	6.06	0.11
Total VFA, Mmol	107.1	78.5	78.1	73.0	1.1
Ruminal VFA, mol/100 mol					
Acetate	58.0	58.1	60.0	62.9	4.6
Propionate	33.2	35.4	31.0	27.3	4.8
Butyrate	8.7	6.4	8.9	9.7	1.1
Methane production[b]	0.46	0.44	0.49	0.54	0.07

[a]C = coarse grind (density = 0.55), M = medium coarse grind (density = 0.50) and F = fine grind (density = 0.45).[b]Methane moles/mol de glucose equivalent fermented

Table 4: Treatment effects on characteristics of ruminal and total tract digestion

		Dry-rolled corn[a]			
Item	SFC	FG	MG	CG	SEM
Replicates	4	4	4	4	
Intake, g d^{-1}					
DM	3,130	3,130	3,130	3,130	
OM	2.942	2.947	2.947	2.955	--
Strach	1.544	1.441	1.462	1.462	--
ADF	239	2.55	2.52	244	--
N	56	60	61	58	--
GE, Mcal/d	13.8	13.6	13.7	13.8	--
Ruminal degestion, %					
OM[b]	68.2	61.4	58.0	59.5	7
Strach[b]	84.4	74.2	68.3	75.1	9
ADF	28.0	30.0	33.9	29..2	9
Feen N	81.1	76.5	81.3	74.5	7
Microbial efficiency[c]	20.1	26.2	82.4	23.9	2.6
Nitrogen efficiencd[d]	0.93	1.01	0.93	0.97	0.04
Postruminal					
OM	61.3	57.7	56.3	58.4	4.6
Strach	90.0	87.5	73.2	75.8	6.2
ADF	18.4	12.1	6.3	14.7	11.0
N	72.4	68.9	65.6	67.9	2.7
Total tract digestion, %					
OM[b]	82.2	76.9	76.9	77.7	1.9
Strach[ef]	98.6	96.6	94.0	93.9	1.0
ADF	41.5	39.0	39.5	40.5	4.9
N[b]	73.7	67.2	67.3	67.9	2.4
DE, %	78.8	72.4	73.1	75.0	4.2
DE, Mcal/ kg[b]	3.48	3.16	3.20	3.32	0.02

[a]C = coarse grind (density = 0.55), M = medium coarse grind (density = 0.50) and F = fine grind (density = 0.45). [b]DRC vs SFC, $p>0.10$. [c]Grams microbial N/kg organic matter fermented.[d]Non-ammonia N leaving abomasum/N intake.[e]DRC vs SFC, $p>0.05$. [f]Linear effect of degree of dry-rolled processing, $p>0.10$

report (Scott *et al*., 2003; Corrona *et al*., 2006), steam flaking corn increased proportion of grain that having a particle size distribution of greater than 4 mm (64 vs 33, 54 and 60%, respectively for SFC, DRC-FG, DRC-MG and DRC-CG).

Treatment effects on ruminal pH, VFA profiles and estimated methane production are shown in Table 3. Ruminal pH 4 h after feeding averaged 5.91 and was not affected ($p>0.10$) by treatments. Accordingly to NRC (1996), observed ruminal pH was lightly higher (3.4%) than expected and this effect may be due to the inclusion of sodium bicarbonate (0.87%; Table 1) in the experimental diets. Even so, the pH value observed here is consistent with those obtained at similar experimental conditions i.e., level of grain, DM intakes as % of BW and time of sampling (Corrona *et al*., 2006; Zinn *et al*., 1995; Sindt *et al*., 2006) Consistent with Galyean *et al*. (1976), Barajas and Zinn (1998) and Zinn *et al*. (1998), grain processing did not affected pH, VFA molar proportion and methane production. However, numerous studies (Zinn *et al*., 2002; Corrona *et al*., 2006; Cooper *et al*., 2002) have reported decreased ruminal pH and acetate, increased propionate and reduced methane production due to steam flaking corn.

Treatment effects on site and extent of digestion are shown in Table 4. Coarseness of grind of DR corn did not affect ($p>0.10$) ruminal digestion of OM, N, starch and ADF. Harmon *et al*. (2004) indicate that the ruminal digestion of starch averaging 77% when starch is consumed in a wide range of intake of 1 to 5 kg d^{-1}. In the present study, starch intake and ruminal digestibility of starch averaged 1.47 kg d^{-1} and 75.5%, respectively. Ruminal starch digestibility was greater (85 vs 73%, $p>0.10$) for SFC than for DRC treatments. Observed ruminal starch digestion for SF corn is in good agreement with the average values of 85% as summarized by Huntington (1997). In another hand, for feedlot cattle, ruminal digestibility of starch in DR corn ranged from 68 to 76% (Zinn, 1990; Corrona *et al*., 2006; Zinn *et al*., 1995; Cooper *et al*., 2002 Cole *et al*., 1976) with an average of 71.5%. The 14% greater ($p>0.10$) ruminal starch digestion with SFC explains most of the increase (12.6%, $p>0.10$) in ruminal OM digestion due to steam flaking.

Ruminal digestibility of feed N was similar ($p>0.10$) across treatments averaging 78%. Thus, consistent with previous trials (Zinn, 1990; 1987; Zinn *et al*., 1995), Undegradable Intake Protein (UIP) of corn was not affected by method or degree of processing. Ruminal microbial efficiency averaged 24.8 g of N kg^{-1} of OM fermented in rumen and was not affected ($p> 0.10$) by treatments. The expected microbial efficiency based on NRC (1995) Level 1 was 23.11 g of N kg^{-1} of OM fermented (21.5 vs 24.8 for SFC vs DRC respectively). In the same manner, there were no effects ($p>0.10$) of corn processing on ruminal protein efficiency (NAN leaving abomasum/N intake). In previous studies no differences were detected by processing of corn on protein efficiency (Corrona *et al*., 2006), but in others (Zinn *et al*., 1995; Barajas and Zinn, 1998) protein efficiency was greater for SFC than for DRC. In those cases, the increase in protein efficiency was due to increased MN synthesis related to increased ruminal OM digestion.

There were no effects (p>0.10) of treatments on postruminal digestion. Notwithstanding that the postruminal starch digestion was numerically greater by 14.8% for DRC-FG compared to DRC-CG and DRC-MG, the difference was not statistically significant (p>0.10).

There were no effects (p>0.10) of coarseness of DRC on total tract digestion of OM, N and ADF. Total tract digestion of starch of DRC treatments averaged 94.8%, this result is in close agreement with the value of 95.1% reported by Cooper *et al.* (2002) and Jaeger *et al.* (2006) but 6% greater than that reported by Owens and Zinn (2005). As result of an increase (14.8%, p>0.10) of postruminal starch digestion to DRC-FG treatment mentioned previously, total tract digestion of starch tended (linear effect, p>0.10) to be greater for finely ground corn. However, decreasing density of DRC below 0.55 kg L^{-1} appeared to have minimal effects on characteristics of digestion. Owens *et al.* (1997; 1986) and Gorocica-Buenfil and Loerch (2005) reported that grinding of corn did not improve starch digestibility. Findings obtained in the present study support that the variations observed in total tract digestion for dry rolled corn in several studies are probably due to corn particle size.

Total-tract digestion of OM, starch, N and DE were greater (6.1, 3.9, 8.4 and 7.3%, respectively, p>0.10) for SFC than for DRC treatments. Improved total tract digestibility of OM, starch and N along with little or no change in fiber digestibility has been a consistent observation in studies comparing SFC-with DRC-based diets (Sundt *et al.*, 2006; Cole *et al.*, 1976; Zinn, 1987).

There were no effects (p>0.10) of coarseness of DRC on the energy value of the diet. Similar results were obtained in a growth-performance trial by Loe *et al.* (2006). They observed an identical energy value when compared coarse-rolled (density = 0.60 kg L^{-1}) and fine-rolled corn (density = 0.54 kg L^{-1}) diets. Given that the DE value of SFC corn are 4.10 (NRC, 1996) , the replacement DE values of DRC treatments can be estimated as follows: DE, Mcal kg^{-1} of test cereal = [(DE observed for each diet containing dry rolled corn-DE observed for the diet containing steam-flaked corn)/0.7325]+4.10. The divisor constant (0.7325) represents the amount of DRC in diet (Plascencia *et al.*, 2002). The Ne_m and NE_g (Mg kg^{-1}) of DRC treatments can be estimated according to the following relationship: NE_m = 0.736DE-0.661; NE_g = 0.877NEm-0.41 (R^2 = 0.998 (Zinn amd Plascencia, 1993; NRC, 1984). In this manner, the average of DE, NE_m and NE_g of DRC treatments were 3.75, 2.10 and 1.43 Mcal kg^{-1}, respectively. The 9% increase in DE value of corn due to steam flaking is consistent with the average improvement of 12% reported in previous metabolism trials (range 8.1 to 19.2%) (Corona *et al.*, 2006; Zinn *et al.*, 1995; Zinn, 1987). The derived NE value for DRC is 4% lower than the corresponding tabular (NRC, 1996). As discussed in previous reports (Zinn *et al.*, 2002) , the NRC (1996; 1984) overestimates the NE value of DRC in the range of 5 to 10%.

CONCLUSION

The feeding value of dry rolled corn is not enhanced by reducing the particle size of the kernels beyond to that obtained following coarse rolling.

ACKNOWLEDGEMENT

Author acknowledge Alberto Barreras Serrano for his advice in the statistical handling of the data.

REFERENCES

AOAC, 1984. Official methods of analysis (12th Edn.). Association of Official Analytical Chemists, Washington, D.C.

Barajas, R. and R.A. Zinn, 1998. The feeding value of dry-rolled and steam-flaked corn in finishing diets for feedlot cattle: Influence of protein supplementation. J. Anim. Sci., 76: 1714-1752.

Bergen, W.G., D.B. Purcer and J.H. Cline, 1968. Effect of ration on the nutritive quality of rumen microbial protein. J. Anim. Sci., 27: 1497-1501.

Cole, N.A., R.R. Jhonson and F.N. Owens, 1976. Influence of roughage level and corn processing method on the site and extent digestion by beef steers. J.Anim. Sci., 43: 490-496.

Cooper, R.J., C.T. Milton, T.J. Klopfenstein, T.L. Scott, C.B. Wilson and R.A. Mass, 2002. Effect of corn processing on starch digestion and bacterial crude protein flow in finishing cattle. J. Anim. Sci., 80: 797-804.

Corona, L., F.N. Owens and R.A. Zinn, 2006. Impact of corn vitreouness and processing on site and extent of digestion by feddlot cattle. J. Anim. Sci., 84: 3020-3031.

Galyean, M.L., D.G. Warner and R.R. Johnson, 1976. Site and extent of starch digestion in steers fed processed corn rations. J.Anim. Sci., 43: 1088-1094.

Gorocica-Buenfil, M.A. and S.C. Loerch, 2005. Effect of cattle age, forage level and corn processing on diet digestibility and feedlot performance. J Anim. Sci., 83: 705-714.

Goering, H.K. and P.J. Van Soest, 1970. Forage Fiber Analysis.Apparatus, Reagents, Procedures and Some Applications. ARS Agric. USDA, pp: 379.

Harmond, D.R., L.M. Yamka and L.A. Elam, 2004. Factors affecting intestinal starch digestion in ruminants: A Rev. Can. J. Anim. Sci., 84: 309-318.

Hungtington, G.B., 1997. Starch utilization by ruminants: Basics to the bunk. J. Anim. Sci., 75: 852-.867.

Hill, F.N. and D.L. Anderson, 1958. Comparison of metabolizable energy and productive determinations with growing chicks. J. Nutr., 64: 587-603.

Hicks, C.R., 1973. Fundamental concepts in the design of experiments. Holt, Rinehart and Winston, Inc.

Jaeger, S.L., M.K. Luebbe, C.N. Macken, G.E. Erickson, T.J. Klopfenstein, W.A. Fithian and D.S. Jackson, 2006. Influence of corn hybrid traits on digestibility and the efficiency of gain in feedlot cattle. J. Anim. Sci., 84: 1790-1800.

Loe, E.R., M. L. Bauer and G.P. Lardy, 2006. Grain source and processing in diets containing varying concentrations of wet corn gluten feed for finishing cattle. J. Anim. Sci., 84: 986-996.

NRC, 1984. Nutrient Requirements of Beef Cattle (6th Edn.), National Academy of Press, Washington DC.

NRC., 1996. Nutrient Requirements of Beef Cattle (7th Edn.), National Academy of Press, Washington DC.

Owens, F.N., R.A. Zinn and Y.K. Kim, 1986. Limits to starch digestion in the ruminant small intestine. J. Anim. Sci., 63: 1634-1648.

Owens, F.N., D.S. Secrist, W.J. Hill and D.R. Gill, 1997. Effect of grain source and grain processing on performance of feedlot cattle: A Rev. J. Anim. Sci., 75: 868-879.

Owens, F.N. and R.A. Zinn, 2005. Corn grain for cattle: Influence of processing on site and extent of digestion. Pages 86-112 in 20th Annual Southwest Nutr. Conf., Phoenix, AZ. Univ. Arizona, Tucson.

Plascencia, A., E.G. Arellano, M.A. López-Soto and R.A. Zinn, 2002. Comparative study on the site and digestion rate of N and starch fraction of four steam-flaked cereals in finishing diets for feedlot steers. Vet Méx., 34: 371-386.

Scott, T.L., C. T. Milton, G.E. Erickson, T.J. Klopfenstein and R.A. Stock, 2003. Corn processing method in finishing diets containing wet corn gluten feed. J. Anim. Sci., 81: 3182-3190.

Sindt, J.J., J.S. Drouillard, E.C. Titgemeyer, S.P. Montgomery, E. R. Loe, B.E. Depenbusch and P.H. Walz, 2006. Influence of steam-flaked corn moisture level and density on the site and extent of digestibility and feeding value for finishing cattle. J. Anim. Sci., 84: 424-432.

Wolin, M.J., 1960. A theorical rumen fermentation balance. J. Dairy Sci., 43: 1452-1459.

Zinn, R.A. and F.N. Owens, 1986. A rapid procedure for purine measurement and it use for estimating net ruminal protein synthesis. Can J. Anim. Sci., 66: 157-166.

Zinn, R.A., 1987. Influence of lasalocid and monensin plus tylosin on comparative feeding value of steam-flaked versus dry-rolled corn diets for feedlot cattle. J. Anim. Sci., 65: 256-266.

Zinn, R.A., 1990. Influence of steaming time on site of digestion of flaked corn in steers. J. Anim. Sci., 68: 776-781.

Zinn, R.A. and A. Plascencia, 1993. Interaction of whole cottonseed and supplemental fat on digestive function in cattle. J. Anim. Sci., 71: 11-17.

Zinn, R.A., C.F. Adam and M.S. Tamayo, 1995. Interaction of feed intake level on comparative ruminal and total tract digestion of dry-rolled and steam-flaked corn. J. Anim. Sci., 73: 1239-1245.

Zinn, R.A., E.G. Alvarez, M.F. Montaño, A. Plascencia and J. Ramirez, 1998. Influence of tempering on the feeding value of rolled corn in finishing diets for feedlot cattle. J. Anim. Sci., 76: 2239-2246.

Zinn, R.A., F.N. Owens and R.A. Ware, 2002. Flaking corn: Processing mechanics, quality standards and impacts on energy availability and performance of feedlot cattle. J. Anim. Sci., 80: 1145-1156.