INFLUENCE OF PROCESSING METHOD ON THE DIGESTION OF CORN STARCH BY STEERS

By

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CHAPTER I

INTRODUCTION

Cereal grains provide the major portion of energy and a considerable amount of protein in beef cattle finishing rations today. Corn grain is undoubtedly the most frequently fed cereal grain in these rations. Obviously any processing method which improves efficiency of corn utilization and thus, reduces overall production cost is of great importance.

Considerable information is available in the literature on the advantages of various processing methods. Many workers have found improved efficiency of feed utilization and in some cases, increased rate of gain in beef cattle fed processed corn. The obvious question is why does corn processing sometimes result in increased efficiency of utilization by beef cattle?

The purpose of the research reported herein was to provide additional information concerning the above question. Corn grain is comprised largely of starch, roughly 70 to 75%. Ruminants digest starch at one of two sites - ruminally by microbial action and intestinally by the action of endogenous enzymatic secretions as in monogastric animals. If corn processing alters the site and/or extent of starch digestion in the digestive tract of cattle, the efficiency of grain utilization might also be altered. Thus additional knowledge concerning the site and extent of starch digestion in processed corn rations may aid our understanding of the effects of processing.

The purpose of this study was to investigate the site and extent of starch digestion in corn grain processed by various methods. Corn processing techniques examined were: 1) steam flaking, 2) dry rolling and high moisture processing either by 3) grinding and ensiling or 4) propionic acid treatment of whole corn.

CHAPTER II

REVIEW OF LITERATURE

Nutritive Value of Processed Corn

Recent changes in the beef feeding industry have encouraged extensive use of cereal grains in finishing rations. In the feedlot industry, cereal grains commonly comprise from 80 to 90% of finishing rations. Improving the efficiency of grain utilization is thus of great economic importance to feeders.

Corn is the most widely fed of all cereal grains. Various methods of processing corn have been investigated to assess their effect on animal efficiency. Among the most commonly used methods are dry rolling, grinding, flaking by heat and moisture treatment and high moisture processing.

Dry Rolling and Grinding

Dry rolling and grinding are often referred to as conventional methods of corn processing. Grinding is usually accomplished by passing the grain through a hammermill with the final product varying widely in degree of fineness. Dry rolling, also referred to as cracking, is accomplished by passing the grain through rollers which are usually grooved on the surface. The final product may vary in particle size from very small to coarse, and is influenced by roller weight, pressure and spacing, moisture content of the grain and rate of grain flow (Wagner, Totusek and Gill, 1973).

Henderson and Geasler (1971) in a summary of 13 cattle feeding trials at various experiment stations reported that feeding dry ground and rolled corn resulted in a 5% improvement in both rate of gain and feed efficiency as compared to dry whole shelled corn when corn comprised less than 70% of the ration. When corn made up 70 to 80% of the ration, rate of gain and feed efficiency on whole shelled and dry ground or rolled corn were similar. However, whole shelled corn appeared to slightly stimulate rate of gain when fed as 80% or greater of the ration (2.46 lb. vs. 2.34 lb. for whole and dry ground or rolled corn, respectively). Vance et al. (1971) observed improved rate of gain and feed efficiency in steers fed all concentrate whole shelled corn vs. crimped corn rations. However, when roughage level was increased to greater than 10 pounds corn silage per day, crimped corn was superior to whole shelled corn. Thus, the differences between whole shelled and dry rolled or ground corn may be related to the roughage level in the ration.

In agreement with these results are those of Hixon, Hatfield and Lamb (1969) who fed rations containing 88.6% corn in either the whole shelled or dry rolled form. Feed efficiency was slightly improved and average daily gain significantly ($p < 0.05$) improved when steers received whole shelled corn as compared to dry rolled corn (1.81 vs. 1.56 kg respectively).

In an Ohio study, Vance et al. (1970) compared whole shelled, dry ground, and steam flaked corn in all concentrate, 10% corn cob and 4% artificial roughage rations. No effect was observed on rate of gain due to physical form of the corn. Steers fed steam flaked corn were more efficient than those fed dry ground or whole shelled corn which were similar. In all concentrate rations, the form of corn fed had no apparent effect on the percent of acetic or propionic acids in rumen fluid.

No advantage to processing was noted by Burkhardt, Embry and Luther (1969) in a study comparing whole shelled, dry rolled, reconstituted and steam flaked corn. Rate of gain and feed efficiencies were similar on all treatments. Johnson, Matsushima and Knox (1968) observed a 4 to 6% increase in dry matter digestion in flaked as compared with rolled corn but no differences in ruminal volatile fatty acid ratios.

Butterbaugh and Matsushima (1974), comparing the feeding value of combinations of processed corn in feedlot rations high in silage, concluded that the inclusion of dry ground corn in rations containing high moisture corn would be of benefit in increasing dry matter intake and maintaining a higher rate of gain. A depressed rate of gain and poorer feed efficiency were noted, however, when dry ground corn was fed with steam flaked corn.

Heat and Moisture Processing

Steam flaking by heat and moisture treatment is a more modern processing technique than dry rolling or grinding. Flaking is accomplished by subjecting the grain to steam at atmospheric pressure for 15 to 30 minutes prior to rolling. Large, heavy rollers are set to produce a very thin, flat flake with a bushel weight of 22 to 28 pounds and a moisture level of 16 to 20%. Flaking results in a rupturing of the starch molecule known as gelatinization. The level of gelatinization can be influenced by any variation in the above factors (Wagner, Totusek and Gill, 1973).

Phillipson (1952) reported that feeding flaked corn resulted in an alteration of the ruminal acetate to propionate ratios. A greater percentage of propionate was found in lambs fed steam flaked corn, indicating that potentially more energy could be available by this technique. Moreover, improved feed efficiencies with no difference in gain has been observed when lambs were fed flaked vs. whole shelled corn in rations containing 45 to 50% hay (Jordan, 1965). Henderson and Geasler (1971) in a summary of 9 trials conducted throughout the country reported no apparent change in daily gain, but a 7.3% improvement in feed efficiency over grinding or cracking when yearling steers were fed high concentrate, steam flaked corn rations.

Vance _et al_. (1970) also reported improved feed efficiency on steam flaked corn compared to whole shelled and dry ground corn in all concentrate diets. Inclusion of 10% corn cobs or 4% artificial roughage to the diet did not alter the improvement in feed efficiency obtained from steam flaking. No differences were observed in rate of gain among treatments. Net energy for maintenance plus production was greater for steam flaked rations. In contrast, McLaren _et al_. (1970) compared whole shelled, extruded and steam flaked corn at 85 to 95% of the ration. No improvement in rate of gain or feed efficiency was observed for steam flaking as compared to the other processing methods.

In a digestion and metabolism study, Johnson, Matsushima and Knox (1968) compared 70 to 80% concentrate rations composed of either dry rolled or steam flaked corn. Flaking resulted in disruption of the starch granule as measured by loss of birefringence, a 9 hour faster rate of passage through the alimentary tract and decreased energy losses in the form of methane gas. An increase of from 6 to 10% in energy retention was also observed upon flaking.

High Moisture Processing

High moisture processing and storage of corn grain is by no means a new technique; however, it has only recently come into extensive use. According to Wagner, Totusek and Gill (1973), high moisture processing can be divided into two categories: high moisture harvesting and reconstitution.

High moisture harvested grain is typically harvested at a moisture level of around 30%. Since grains are physiologically mature at 38 to 40% moisture, no additional dry matter will accumulate as the grain dries further. The grain may be stored in a trench silo as a ground product or in oxygen-limited silos in the whole or ground form. More recently, organic acids have been added to moist whole shelled grain as preservatives which permits open air storage.

Reconstitution differs from high moisture harvesting in that dry grain is reconstituted to a moisture content of 25 to 30% and stored whole under oxygen-limited conditions for approximately 20 days or more prior to feeding. It is recommended the grain be stored in the whole form and ground or rolled prior to feeding to obtain maximum benefit from reconstitution.

Beeson and Perry (1958) reported that high moisture ground ear corn (32.2% H_2O) resulted in a 12 to 15% saving in feed when compared to regular ground ear corn (17.7% H_2O). Steers receiving high moisture corn gained 0.13 to 0.23 pounds more per day than those fed dry corn, but the difference was not significant.

In agreement with these results is the work of Forsyth, Mowat and Stone (1972). When steers were fed a ration containing 78% corn processed either by grinding and ensiling at 30% moisture, treatment with 1.5% propionic acid at 30% moisture or drying to 13% moisture, rate of gain was slightly but not significantly faster for both high moisture processed grains. Both acid treated and ensiled high moisture corns were utilized more efficiently than dry corn. When reconstituted propionic acid treated corn was compared to dry shelled corn, no differences were observed in either gain or feed efficiency.

Work at the Oklahoma station (Martin et al., 1970) demonstrated that high moisture harvested (30% H_2O) ground corn was utilized 11.9% more efficiently than dry ground corn. Henderson and Bergen (1970) reported steers fed an 80% dry rolled corn ration gained 4 to 6% faster but required 13 and 11% more feed per pound of gain than those fed 80% reconstituted ground and 80% high moisture harvested ground corn rations, respectively. High moisture whole shelled corn stored in either upright silos, sealed bins or concrete bunkers produced an average improvement of 7% in daily gain and a 4% improvement in feed efficiency over dry whole shelled corn when fed to finishing cattle (Tolman and Guyer, 1974). Ground ensiled high moisture corn resulted in decreased gain and increased feed efficiency when compared with dry corn. Several other authors have demonstrated an improvement in efficiency with no subsequent improvement in rate of gain (Ware, Self and Hoffman, 1974; Tonroy, Perry and Beeson, 1974; Harris et al., 1971).

Jorgensen et al. (1970) reported high moisture (32% H_2O) corn to be equal to dry shelled corn for milk production as well as for other production traits in dairy cows. Similar results were reported by Clark et al. (1973) who fed dry corn, ensiled high moisture corn and propionic acid treated corn to dairy cows. MacLeod, Grieve and Freeman (1974) fed 24% moisture corn treated with either 0.95% propionic acid, 1.15% acetic:propionic acids (40:60) or dry shelled corn and concluded corn treated by any of these methods would give satisfactory results with lactating dairy cows.

In contrast to the reports of other authors, Hueberger et al. (1959) reported slower gains and lower ($p < 0.05$) feed efficiencies in heifers fed high moisture harvested corn stored at 36% moisture as compared to dry shelled corn. However, when moisture level was lowered to 24 or 29%, gains and feed efficiencies were similar to dry shelled corn fed heifers. These authors also reported no significant differences in dry matter, ether extract, protein and crude fiber digestion coefficients among the rations.

Mohrman et al. (1959) also found no significant differences in dry matter or nitrogen digestion or energy retention in lambs fed either dried shelled corn or high moisture corn ensiled at 25 or 30% moisture. Similar results were reported by Barney and Klopfenstein (1974). Tonroy, Perry and Beeson (1974) reported higher digestibilities ($p < 0.05$) of crude protein for high moisture ensiled corn as compared to dry corn, reconstituted ensiled and organic acid treated high moisture corn. No differences were noted, however, in dry matter, energy, organic matter, crude fiber and NFE digestibilities. White, et al. (1973) found no difference in digestion of dry matter, starch, energy or crude protein when lambs were fed rolled corn treated by field drying, roasting at 149°C, high moisture storage at 25 to 30% moisture in oxygen-limited silos, reconstitution to 30% moisture or treatment of 30% moisture corn with 57% acetic:40% propionic acids at the 1.5% level.

Several authors have reported that chemical changes occur upon high moisture ensiling of corn that may result in reduced feed intake. Sprague and Breniman (1969) indicated poor performance in feedlot cattle fed ensiled high moisture corn may be related to the corn's crude protein which is soluble in 70 to 80% ethanol. These authors felt poor apetite, gains and symptoms similar to ammonia toxicity might be related to high soluble protein levels.

Danley and Vetter (1974) demonstrated an increase in total soluble nitrogen upon ensiling corn as compared to heat treatment of corn grain by drying or steaming. Prigge, Johnson and Williams (1974) indicated that soluble nitrogen content of ground ensiled high moisture corn increased with days of ensiling. These authors also reported that soluble nitrogen content of corn ensiled in the whole shelled form was less than that of ground ensiled corn and pointed out the need for further investigating the influence of nitrogen solubility on animal performance.

Site and Extent of Starch Digestion in Processed Grains

Site of starch digestion in different segments of the digestive tract of ruminants has been studied in several cereal grains processed by various methods. Information on corn grain alone, however, is limited. This review will thus concentrate on sorghum and barley in addition to corn.

Sorghum

Sorghum appears to respond more to processing than other grains, not only in terms of increased animal performance but in terms of increased digestibility. McNeill, Potter and Riggs (1971) evaluated the ruminal and postruminal digestibility of sorghum processed by grinding, steam flaking, reconstitution and micronizing. Significantly more starch ($p < 0.05$) was digested in the rumen on steers fed steam flaked and reconstituted sorghum. Postruminal and total tract starch digestion were nearly complete with no differences among treatments. However, steers in this study were fed only 4 kg dry matter per day which may have tended to equalize differences in intestinal starch digestibility.

In contrast, Hinman and Johnson (1974a) found no significant differences between ruminal digestibilities of dry rolled, micronized, steam flaked and ground sorghum. However, dry rolled sorghum had significantly less starch digested postruminally (67.7% compared to 94.4% for all other rations combined). Steers in this study received more dry matter per day than those in the study of McNeill, Potter and Riggs (1971) discussed above.

Degree of processing has also been investigated. Hinman and Johnson (1974b) compared low, medium and high levels of micronization on 84% sorghum rations and found no difference in ruminal, postruminal and total starch digestion among levels. Steaming sorghum under atmospheric conditions and at 3.5 kg/cm^2 was compared by Holmes, Drennan and Garrett (1970). Sorghum steamed at 3.5 kg/cm^2 was digested to a greater extent ruminally (5% increase) than that steamed under atmospheric pressure. The difference, however, was not significant.

Waldo (1974) summarized eight experiments concerning sorghum grain and concluded that ruminal digestibility was an average of 76% ± 22.4% for all processing techniques.

Barley

Barley starch appears to be highly digestible in the rumen and thus less affected by processing than sorghum. Several authors have shown the ruminal digestion of barley starch to be greater than 90% in both cattle and sheep fed high concentrate rations (Macrae and Armstrong, 1969; Thivend and Journet, 1968; Orskov, Fraser and Kay, 1969; Orskov, Fraser and McDonald, 1971 a and b, Topps, Kay and Goodall, 1968; Topps *et al.*, 1968). These authors also indicated almost complete intestinal and total tract digestion of the starch.

Waldo (1974) summarized 23 trials investigating the site of digestion of barley starch. A value of 94% ± 2.4% was reported as the average ruminal digestion of the starch in barley based rations. He concluded there is little variation due to different lots of barley, species of livestock to which it is fed, processing method, percentage in the ration or level of intake.

Corn

Corn starch seems to be somewhat intermediate between barley and sorghum starch in terms of extent of ruminal fermentation. Waldo (1974) summarized 30 experiments and concluded the digestion of corn starch in the rumen was 78% ± 12.5%. He noted considerable variation due to processing and level of intake.

Little, Mitchell and Reitnour (1968) infused a corn starch slurry into the abomasum of steers at a level of 200, 400 and 600 g twice daily. As the level of infusion increased, more starch was found in the posterior ileum and feces, indicating a biological maximum for starch digestion in the small intestine and the need for considerable starch breakdown in the rumen. In contrast, Wright, Grainger and Marco (1966) fed a 64% cracked corn ration *ad libitum* to sheep and concluded the ruminant has adequate capacity to digest starch in the small intestine.

Waldo, Keys and Gordon (1971) fed increasing amounts of cracked corn to steers at a level of 70 g air dry feed per $kg^{3/4}$ per day. No significant differences were found in the percentage of starch digested ruminally; however, large quantities of starch did escape fermentation. Total starch digestibility was found to be greater than 99% for all rations. Karr, Little and Mitchell (1966) fed similar cracked corn rations and found large amounts (35 to 40%) of starch escaped ruminal fermentation. Digestion of starch in the small intestine decreased as the percent corn in the ration increased. Total tract digestion was again almost complete. Thivend and Journet (1970) also observed increasing amounts of starch escaping ruminal fermentation as the level of corn in the ration increased.

Orskov, Fraser and McDonald (1971) reported approximately 21 to 22% of unprocessed corn starch escaped ruminal fermentation. Processing corn by methods other than rolling or grinding appears, however, to increase ruminal fermentation. Beever, Coehlo da Silva and

Armstrong (1970) compared diets based on ground and steam flaked corn. Ruminal digestion of ground corn was 78.1% compared to 95.7% for flaked corn. Similar results with steam flaked corn have been reported by other authors (Macrae and Armstrong, 1969; Orskov, Fraser and Kay, 1969; Nicholson and Sutton, 1969).

The site of digestion of high moisture processed corn diets has recently been investigated by McKnight _et al_. (1973). Heifers were fed 66% corn rations processed by dry grinding, high moisture grinding and ensiling and treatment of high moisture corn with either of two different organic acids in a 4 × 4 Latin square design. All rations were ground before feeding. Only 47.3% of ration starch was digested ruminally in dry corn fed heifers compared to 81.4% on ensiled corn. Ruminal digestion of starch in high moisture corn treated with propionic or an acetic, propionic acid mixture was reported to be 63.0 and 75.7%, respectively. However, none of these differences were significant. Total tract energy digestibilities were significantly ($p < 0.05$) greater for all high moisture diets, possibly due to increased ruminal fermentation of starch in these rations.

CHAPTER III

INFLUENCE OF PROCESSING METHOD ON THE DIGESTION OF CORN STARCH BY STEERS[1,2,3]

Summary

A 4 × 4 Latin square design was employed to study the site and extent of starch digestion in steers fed processed corn grain. Steers fitted with permanent rumen and abomasal cannulae were fed a 78% corn ration (DM basis). Intake was approximately 4.5 kg/day with the rations differing only in method of processing. Corn was processed by 1) dry rolling (DR), 2) steam flaking (SF), 3) high moisture grinding and ensiling (GHMC) and 4) high moisture harvesting and treating with propionic acid (AHMC). Digestion of dry matter, organic matter and starch, ruminally and post ruminally, were determined by the lignin ratio technique.

Ruminal starch digestibilities were 89.3%, 82.9%, 77.8% and 62.8% for GHMC, SF, DR and AHMC, respectively, DR and AHMC being significantly lower ($p < 0.05$) than GHMC. Ruminal starch digestion on AHMC was lower ($p < 0.05$) than on all other rations. No significant differences

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[1] Journal Article of the Agricultural Experiment Station, Oklahoma State University, Stillwater.

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were observed in intestinal starch digestibility among rations. Total tract starch digestibilities were higher ($p < 0.05$) for GHMC (99.1%) and SF (99.1%) than for AHMC (95.8%) and DR (96.3%) reflecting higher ruminal starch digestibility. Ruminal, intestinal and total dry matter and organic matter digestibilities followed patterns similar to starch digestibilities.

Degree of gelatinization was greatest for SF grain as was *in vitro* gas production from incubation with yeast and amyloglucosidase, indicating a greater disruption of starch granules. *In vitro* ruminal dry matter disappearance was greatest ($p < 0.05$) at 3, 6, 9 and 12 hours for GHMC grain possibly due to increased protein solubilization and higher soluble non-protein nitrogen levels in the *in vitro* culture. *In vivo* rumen ammonia levels were higher ($p < 0.05$) at 1 and 2 hours post feeding for GHMC than the other rations. Rumen pH was lower ($p < 0.05$) at 2 and 4 hours post feeding for GHMC as compared to all other rations. Total concentrations of volatile fatty acids at 4 hours post feeding were greatest for GHMC followed by SF, DR and AHMC. Differences between all rations were significant ($p < 0.05$).

Introduction

Considerable evidence exists that corn (*zea mays indentata*) utilization may be improved by processing. Improvements in feed efficiency when processed corn is fed to cattle might be due to increased starch digestion in one or more segments of the ruminant digestive tract. Orskov, Fraser and McDonald (1971) reported approximately 21 to 22% of unprocessed corn starch escaped ruminal fermentation. Beever, Coehlo da Silva and Armstrong (1970) found ruminal digestion of ground corn to be 78.1% compared to 95.7% for flaked corn. Moreover, considerably more ruminal fermentation of starch has been observed for high moisture ensiled corn than dry corn in heifers (McKnight _et al._, 1973). Observations by Little, Mitchell and Reitnour (1968) indicate a biological maximum for starch digestion in the ruminant small intestine.

The purpose of this study, therefore, was to investigate the site and extent of starch digestion of corn grain processed by the following methods: 1) dry rolling, 2) steam flaking and high moisture harvesting and processing either by 3) grinding and ensiling or 4) propionic acid treatment of whole corn.

Experimental Procedures

Four Hereford steers (429 kg) fitted with permanent rumen and abomasal cannulae were housed in individual metabolism stalls and fed rations containing 78% processed corn (Table I). A 4 × 4 Latin square design with 14 day periods was employed with steers being fed twice daily at 8:00 a.m. and 8:00 p.m., equal amounts at each feeding.

Grains were processed by the following four methods. Dry rolled corn (DR) was prepared by passing dry corn (12% H_2O) through a set of rollers to crack the kernels. Steam flaked corn (SF) was prepared by steaming the grain at atmospheric pressure at 100°C for 20 minutes prior to rolling, yielding a final product with a moisture content of 19%. High moisture ground, ensiled corn (GHMC) was prepared by coarse grinding corn grain (28.5% H_2O) in a hammermill followed by ensiling in a concrete trench silo. High moisture propionic acid treated corn (AHMC) was prepared by treating whole shelled corn grain (22.2% H_2O) with a

TABLE I

COMPOSITION OF CORN RATIONS

Ingredient	International Reference No. (IRN)	% D.M. Basis
Corn, dent yellow grain (4)	4-02-935	78
Cotton, seed hulls (1)	1-01-599	15
Cotton, seeds w some hulls, solv-extd grnd, mn 41% protein mx 14% fiber mn 0.5% fat (5)	5-01-621	4.55
Calcium phosphate Dibasic, commercial (6)	6-01-080	0.50
Calcium, carbonate Commercial, mn 38% ca (6)	6-01-069	0.70
Urea, mn 45% N (5)		0.70
Trace mineralized salt		0.50
Aurofac-50 (200 mg/kg)[a]		+
Vitamin A, palmitate Commercial (7) (165 mg/kg)[b]	7-05-143	+
Vitamin D_3, Commercial (7) (44 mg/kg)[c]		+

[a]11.04 mg chlortetracycline per kg feed.

[b]30,000 IU per g, provides 4950 IU per kg feed.

[c]10,000 IU per g, provides 440 IU per kg feed.

commercial mixture of propionic acid at a level of 9.5 g acid/kg moist grain. Grain processed by each method was obtained from separate sources, SF and GHMC grain being obtained from commercial feedlots.

Samples of rumen contents were obtained at 0, 1/2, 1, 2, 4 and 8 hr. post feeding on days 5 and 6 of each 14 day period. Samples were strained through 4 layers of cheesecloth, and approximately 0.5 ml of a 20% sulfuric acid solution was added per 100 ml of rumen fluid to stop microbial action. Prior to straining through cheesecloth, a pH measurement was obtained on each sample. Rumen ammonia (NH_3-N) was determined on the strained fluid samples at 0, 1/2, 1, 2, and 4 hr. post feeding by Kjeldahl distillation over Magnesium oxide (A.O.A.C., 1960). Volatile fatty acid (VFA) analysis of samples obtained 4 hr. post feeding was conducted by the procedure of Erwin, Marco and Emery (1961) with a Bendix Series 2500 Gas Chromatograph. Column packing and gas flow specifications were reported by Hinman and Johnson (1974).

A total collection of feces was obtained on days 11 through 14 of each 14 day period. Feces was weighed daily and a 10% aliquot retained. Aliquots from each of the four days were composited, mixed and a sub-sample dried at 60°C for 48 hr. followed by grinding through a 1 mm screen in a Wiley mill. Samples of abomasal contents were obtained via cannula on days 13 and 14 of each period at 0, 2, 4, 6, 8 and 10 hr. post feeding. Two hundred gram aliquots were taken under continuous stirring of the fluid at each 2 hour sampling time, all 200 g aliquots being composited at the end of the 12 hr. collection period. Composite samples of abomasal contents were then dried at 60°C for 48 hr. followed by grinding through a 1 mm screen in a Wiley mill. Samples of rations were obtained on days 7 through 14 of each period, composited and ground in the same manner as fecal and abomasal samples. Dry matter, ash, starch, acid detergent fiber (ADF) and lignin analyses were conducted on ration, fecal and abomasal samples. Starch was determined as α-linked glucose polymers by the enzymatic procedure of Macrae and Armstrong (1968). ADF and lignin were determined by the permanganate oxidation procedure of Van Soest and Wine (1968). Starch digestibilities prior to the abomasum were calculated by the lignin-ratio technique. Crude protein was determined on ration and fecal samples by the Kjeldahl procedure.

Soluble nitrogen (SN) of the rations was determined by extracting ration samples in an "Ohio Aqueous Buffer Solution" (Johnson, 1969) with an ionic strength of 0.14 and a pH of 5.5 using a modified procedure of Wohlt, Sniffen and Hoover (1973). Soluble non-protein nitrogen (SNPN) of the rations was determined on a 50 ml solution containing the SN fraction by precipitating the protein with 5 ml of 1.07 N H_2SO_4 and 5 ml of a 10% Sodium Tungstate solution. The mixture was refrigerated overnight, and the precipitant was separated by centrifugation at 16,000 × G for 10 minutes. Kjeldahl analysis was conducted on the supernatant, and the SNPN was calculated by dividing the amount of nitrogen by the amount of ration per 50 ml.

In vitro dry matter disappearance (DMD) of the processed grains, previously ground through a 1 mm screen in a Wiley mill, was determined at 3, 6, 9 and 12 hr. incubation lengths using procedures outlined by Johnson (1969). Fifteen milliliter of artificial saliva and 10 ml of rumen fluid from a donor steer were added to 0.4 g of ground grain in a previously tared test tube. These tubes were incubated at 39°C for the prescribed length, dried at 100°C for 24 hr., reweighed, and the percent DMD calculated.

In vitro gas production of the same grains was measured hourly for a 6 hour period by a modification of the procedure of Sandstedt *et al*. (1962). Samples of 0.4 gm of the ground grain were incubated with 10 ml of a 0.1% amyloglucosidase solution and 0.25 gm of commercial baker's yeast. Gas production was measured in an inverted buret recovery system. Degree of gelatinization of the processed grains was determined as miligrams maltose released after incubation with beta-amylase (Sung, 1969). Particle size of DR and GHMC grains was determined by the method of Ensor, Olson and Colenbrander, (1970).

Digestibility data were subjected to standard statistical analysis procedures for Latin square designs. Rumen pH and NH_3-N data were analyzed within hours by the same procedures as digestibility data. Means squares for nutrient digestibilities and rumen parameters are shown in the Appendix.

Laboratory evaluation data did not fit the Latin square model and were thus analyzed by different procedures than digestibility and rumen data. *In vitro* gas production data were analyzed within individual hours with runs on different days used to obtain replication. Run × processing method interaction was used an error term to test processing method effects. *In vitro* DMD was analyzed within hours by use of a completely randomized model, assuming each culture tube was a treatment replication. Mean squares for laboratory evaluation data are shown in the Appendix. Tests of significance among treatment means were accomplished by the use of an LSD protected by a preliminary F test.

Results and Discussion

Chemical composition of the rations is shown in Table II. Organic matter (OM), ash, acid detergent fiber (ADF) and lignin content were similar for all rations. Although crude protein (CP) content of the rations was similar, the percent SN and SNPN were considerably higher for GHMC. The increased SN in the ensiled corn is in agreement with work of Sprague and Breniman (1969). Starch content of the rations was somewhat variable possibly due to each grain coming from a different source, however, assuming starch availability is essentially the same for all rations, the only effect this should have is an increased starch intake on rations of higher starch content. Physical characteristics of the processed grains are shown in Table III.

In vitro gas production data (Table IV) demonstrates an increased starch availability in SF grain. More gas was produced ($p < 0.05$) on SF grain after 1, 2 and 3 hours of incubation than on the other grains. Moreover, total gas produced in six hours was higher ($p < 0.05$) on SF grain (98.1 ml/g dry matter) followed by GHMC (71.5), AHMC (63.0) and DR grain (55.8). Gas production appears to indicate to some degree the extent of processing or starch modification. Moreover, SF corn showed a greater gelatinization (Table V) upon incubation with beta-amylase, indicating a greater alteration of the starch granules than in AHMC, DR and GHMC. Disruption of the starch granule following flaking has also been demonstrated by Johnson, Matsushima and Knox (1968).

In vitro DMD of GHMC grain (Table V) was significantly higher ($p < 0.05$) during each incubation period; 3, 6, 9 and 12 hours. The rapid fermentation rate of GHMC grain may be due, in part, to the extensive solubilization of the protein fraction (Table II). Several

TABLE II

CHEMICAL COMPOSITION OF CORN RATIONS

Item	Ration				
	AHMC	SF	GHMC	DR	SEM
Dry matter %	81.1	83.0	74.7	88.2	.18
Organic matter %[a]	96.9	97.4	96.9	96.4	.04
Ash %[a]	3.1	2.6	3.1	3.6	.04
Crude protein %[a,b]	11.8	10.6	12.0	11.7	.32
Soluble nitrogen % of Total N[a]	15.3	7.7	63.6	11.7	.60
Soluble NPN % of Total N[a]	9.5	4.9	56.6	4.3	.23
Acid detergent fiber %[a]	13.9	14.7	13.0	14.9	.36
Permanganate lignin %[a]	4.4	4.1	4.6	3.9	.27
Starch %[a]	65.2	62.4	75.7	68.9	2.40

[a]D.M. basis

[b]Nitrogen × 6.25

TABLE III

PHYSICAL CHARACTERISTICS OF PROCESSED CORN GRAIN

Item	Method of Processing			
	AHMC	SF	GHMC	DR
Sieve Diameter (microns)	% Retained on Screen			
8000	-	-	0.7	1.3
4000	-	-	13.8	41.7
2000	-	-	39.6	39.7
1000	-	-	30.8	9.2
500	-	-	12.7	3.5
250	-	-	1.5	3.0
125	-	-	0.9	1.2
Pan	-	-	-	0.4
Density (g/liter)	663.8	446.3	-	-

TABLE IV

IN VITRO GAS PRODUCTION OF PROCESSED CORN GRAIN[d]

	Hour[e]						
Ration	1	2	3	4	5	6	Total
AHMC	17.6[b]	10.3[bc]	11.3[b]	8.2	8.4	7.2	63.0[bc]
SF	32.4[a]	18.6[a]	17.1[a]	12.4	10.0	7.8	98.1[a]
GHMC	18.7[b]	10.7[b]	12.4[b]	10.2	10.3	9.4	71.5[b]
DR	16.3[b]	9.3[a]	9.5[c]	7.7	6.7	6.7	55.8[c]
SEM	2.7	0.3	0.3	0.8	0.7	0.6	3.2

[abc]Means in a column which do not have the same superscript are significantly different ($p < 0.05$).

[d]Each mean is the average of eight observations.

[e]Values are reported as ml gas/gm dry matter.

TABLE V

IN VITRO DRY MATTER DISAPPEARANCE (DMD) AND DEGREE OF GELATINIZATION OF PROCESSED CORN GRAINS

Processing Method	%DMD[d] Hour				Degree of gelatinization mg maltose/gm grain[e]
	3	6	9	12	
AHMC	10.8[ab]	15.3[a]	20.2[a]	31.2[a]	15.8
SF	13.3[a]	19.3[a]	23.1[a]	33.7[a]	24.1
GHMC	31.4[c]	33.3[b]	41.3[b]	51.4[b]	16.9
DR	9.7[b]	19.5[a]	28.4[c]	34.1[a]	15.4
SEM	1.0	1.4	1.6	1.6	5.8

[abc]Means in a column which do not have the same superscript are significantly different ($p < 0.05$).

[d]Each mean is the average of five observations.

[e]D.M. basis.

authors have demonstrated an increased DMD by adding soluble NPN sources (urea) to in vitro fermentation systems (Galyean, Prigge and Johnson, 1974; Smith and Neumann, 1970). Thus, the rapid DMD of GHMC might be related to its high SN and SNPN content. The DMD of SF grain was somewhat lower than expected, expecially considering the higher gas production observations (Table IV) cited previously. If nitrogen was limiting in the in vitro ruminal culture, however, the much lower SN and SNPN of SF, DR and AHMC grains may have limited DMD to some extent. The possible effects on DMD due to differences in starch availability as a result of processing and soluble nitrogen content from processing are clearly confounded in this case.

Rumen pH (Table VI) was similar on all rations at the 0 hour sampling time and 1/2 hour post feeding, with some difference at 1 hour post feeding. At 2 and 4 hours post feeding, however, rumen pH on GHMC was significantly lower ($p < 0.05$) than on the other treatments. It is interesting to note the decrease in pH observed with GHMC considering the rather low level of intake in this study (approximately 4.5 kg/day). At intake levels similar to those observed under feedlot conditions, the decline in rumen pH post feeding on GHMC might be even greater.

Total concentrations of VFA at 4 hour post feeding (Table VII) were also highest on GHMC ($p < 0.05$); VFA concentrations tended to be inversely related to pH. Molar percentage of acetate was somewhat higher than might be expected on these type rations; however, the low level of intake may account for this observation. Significantly more ($p < 0.05$) acetate and less propionate was produced on DR than on AHMC and GHMC. More ($p < 0.05$) butyric acid was produced on SF than on GHMC and DR. Slightly higher propionate levels observed on AHMC may

TABLE VI

RUMEN pH OF STEERS FED PROCESSED
CORN GRAIN RATIONS

Ration	Hours Post Feeding					
	0	1/2	1	2	4	8
AHMC	6.5	6.4	6.3	6.2^{b}	6.3^{b}	6.4
SF	6.5	6.4	6.2	6.1^{b}	6.1^{b}	6.3
GHMC	6.6	6.4	6.1	5.7^{a}	5.7^{a}	6.4
DR	6.4	6.5	6.4	6.2^{b}	6.2^{b}	6.5
SEM	0.1	0.04	0.06	0.06	0.06	0.08

^{ab}Means in a column which do not have the same superscript are significantly different ($p < 0.05$).

TABLE VII

TOTAL AND MOLAR PERCENTAGES OF VOLATILE FATTY ACIDS IN STEERS FED PROCESSED CORN RATIONS

	Volatile Fatty Acids[e]						
	Total Concentration	Molar %					
Ration	m moles/liter	C-2	C-3	C-4	Iso C-4	Iso C-5	C-5
AHMC	71.36[a]	64.64[a]	20.02[a]	9.74[ac]	1.26[a]	3.00[a]	1.34[a]
SF	104.93[b]	66.19[ab]	18.54[ab]	10.30[a]	0.97[b]	2.92[a]	1.08[b]
GHMC	130.51[c]	64.82[a]	21.55[a]	8.41[bc]	1.00[b]	3.04[a]	1.18[b]
DR	82.94[d]	68.38[b]	16.41[b]	8.11[b]	1.20[a]	4.59[b]	1.31[a]
SEM	3.26	0.91	1.21	0.47	0.03	0.23	0.04

[abcd]Means in a column which do not have the same superscript are significantly different ($p < 0.05$).

[e]Each mean is the average of 16 observations.

reflect the prior treatment of the grain with propionic acid. Similar results with propionic acid treated high moisture corn were reported by McKnight et al. (1973). In addition, higher propionate levels may imply more rapid rumen turnover, lower proteolysis and enhanced starch availability in the lower gut (Ishaque, Thomas and Rook, 1971).

Rumen NH_3-N levels (Table VIII) were significantly higher ($p < 0.05$) on GHMC at 1 and 2 hr. post feeding than on the other rations. Peak NH_3-N values were observed at 1/2 hr. post feeding, with GHMC being significantly greater ($p < 0.05$) than SF and AHMC. These NH_3-N levels are higher than most reported in the literature, possibly as a result of urea addition to all rations. Trends, however, are in agreement with the work of McKnight et al. (1973) who observed higher NH_3-N levels with ensiled high moisture corn than on acid treated high moisture or dry corn. High rumen NH_3-N levels for GHMC are not surprising in view of the high SN and SNPN levels observed (Table II), and likely reflect SN levels.

Total tract digestibilities of crude protein (CP), ash and ADF are shown in Table IX. CP and ADF digestibilities were similar for all rations while ash was quite variable. Ruminal, intestinal and total digestibilities of DM and OM are also given in Table IX. Significantly less ($p < 0.05$) DM was digested ruminally in AHMC, but GHMC, SF and DR were similar in ruminal DM digestion. No significant differences existed between intestinal and total DM digestibility of the rations, however percent intestinal DM digestion of AHMC was highest of the four rations as would be expected from its lower ruminal digestion. Since ash content of abomasal samples varied considerably, OM digestion in the rumen is probably a better indication of processing effects.

TABLE VIII

RUMEN NH_3-N OF STEERS FED PROCESSED CORN GRAIN RATIONS

	Hours Post Feeding				
Ration	0	1/2	1	2	4
AHMC	6.6	21.6[bc]	18.6[b]	11.4[b]	4.9
SF	6.4	18.8[c]	17.1[b]	8.5[b]	2.6
GHMC	9.5	35.5[a]	31.1[a]	18.9[a]	5.3
DR	9.9	28.0[ab]	22.3[b]	12.1[b]	4.6
SEM	1.0	2.3	1.8	1.8	0.6

[abc]Means in a column which do not have the same superscript are significantly different ($p < 0.05$).

TABLE IX

IN VIVO DIGESTIBILITY OF DM, OM, STARCH, CP, ASH AND ADF OF PROCESSED CORN RATIONS

	Ration				
Item	AHMC	SF	GHMC	DR	SEM
DM intake, g	4513	4489	4437	4402	
OM intake, g	4374	4372	4299	4246	
Starch intake, g	2944	2803	3359	3034	
Ruminal DM dig. %	28.4^{a}	45.3^{b}	43.5^{b}	47.4^{b}	3.7
DM entering intestine dig. %	69.6	63.2	65.2	61.9	3.1
Total DM dig. %	78.5	80.4	80.4	79.9	1.0
Ruminal OM dig. %	35.2^{a}	51.7^{b}	50.2^{b}	52.1^{b}	2.9
OM entering intestine dig. %	68.6	61.5	62.9	60.3	3.2
Total OM dig. %	79.9	81.7	81.6	80.6	0.9
Ruminal starch dig. %	62.8^{a}	83.0^{bc}	89.3^{c}	77.8^{b}	3.2
Starch entering intestine dig. %	88.2	94.4	90.8	84.8	3.6
Total starch dig. %	95.8^{a}	99.1^{b}	99.1^{b}	96.3^{a}	0.6
Total CP dig. %	66.0	66.1	66.7	68.4	1.4
Total Ash dig. %	47.0^{a}	30.3^{b}	42.3^{ab}	53.9^{a}	3.5
Total ADF dig. %	39.1	40.1	36.5	45.6	2.3

^{abc}Means in a row which do not have the same superscript are significantly different ($p < 0.05$).

Ruminal OM digestion of AHMC was lower ($p < 0.05$) than the other rations which were similar in ruminal OM digestion. Patterns similar to DM digestion were observed in percent intestinal and total OM digestion. These results concur with those of McKnight et al. (1973) who observed higher ruminal DM and OM digestibilities with ensiled high moisture corn as compared to propionic acid treated or dry corn.

Ruminal, intestinal and total starch digestion of the processed corn rations is shown in Table IX. Starch intake was similar for all rations. Ruminal digestion of starch in GHMC (89.3%) was greatest followed by SF (82.9), DR (77.8) and AHMC (62.8), DR and AHMC being significantly lower ($p < 0.05$) than GHMC. Ruminal starch digestion for AHMC was significantly lower ($p < 0.05$) than all other rations. Similar results were reported by McKnight et al. (1973). Several authors have observed ruminal starch digestibilities greater than 90% with steam flaked corn (Beever, Cochlo da Silva and Armstrong, 1970; Orskov, Fraser and Kay, 1969; Nicholson and Sutton, 1969). The somewhat lower ruminal starch digestibility observed with SF in this study may be largely due to the thick heavy nature of the flake.

It is significant to note that the intestinal digestibility of starch was not greatly different among rations, although SF and GHMC tended to be higher. Whether this observation would hold under higher levels of intake is not known. Total starch digestibilities were significantly greater ($p < 0.05$) for GHMC (99.1%) and SF (99.1) than for DR (96.3) and AHMC (95.8). The lower total starch digestion of AHMC and DR reflects their lower ruminal starch digestion.

Several authors have observed similar rates of gain and feed efficiency when steers were fed either high moisture ensiled or high moisture propionic acid treated corn (Forsyth, Mowat and Stone, 1972; Tonroy, Beeson and Perry, 1974). This might appear puzzling in light of the lower total starch digestibilities of AHMC compared to GHMC in this study. However, if the percent of intestinal starch digestion is the same for these two rations and a lower percentage of starch is digested ruminally in AHMC, more total grams of starch would reach the intestine in AHMC, be degraded enzymatically to glucose and be absorbed intestinally. Black (1971) and Sutton (1971) have pointed out that starch digested intestinally and absorbed as glucose should be more efficiently used than starch fermented in the rumen. Thus, if the high moisture processing and organic acid treatment of whole corn somehow decreases total ruminal starch digestion and increases total intestinal starch digestion, the similarities in feed efficiency and rate of gain might be explained.

This study suggests that processing of corn by high moisture grinding and ensiling and steam flaking results in more *in vivo* total starch digestion than is observed with dry rolled or whole shelled propionic acid treated high moisture corn due to increased ruminal fermentation of starch.

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APPENDIX

TABLE X

AOV FOR STARCH, DM AND OM DIGESTIBILITIES

Source	df	MS								
		Ru. St.	In. St.	Tl. St.	Ru. DM	In. DM	Tl. DM	Ru. OM	In. OM	Tl. OM
Total	15									
Period	3	68.97	35.37	4.63	29.91	4.15	8.83	18.05	6.64	8.55
Animal	3	229.37	88.56	7.71	140.80	87.09	42.94	145.34	68.50	41.32
Ration	3	513.28	63.33	12.71	299.42	46.16	1.10	261.40	54.08	2.70
Error	6	40.05	51.90	1.41	55.16	39.13	3.80	33.95	40.15	2.94

TABLE XI

AOV FOR CP, ASH AND ADF DIGESTION AND RUMEN NH_3-N

Source	df	MS							
		CP	Ash	ADF	NH_3-0	NH_3-1/2	NH_3-1	NH_3-2	NH_3-4
Total	15								
Period	3	13.60	26.02	62.12	11.02	16.04	7.43	17.77	3.60
Animal	3	73.75	200.10	83.25	1.14	28.60	25.18	26.02	9.43
Ration	3	4.93	394.68	59.33	13.68	221.27	157.56	77.14	5.52
Error	6	7.88	48.45	21.60	3.77	21.62	12.91	12.45	1.29

TABLE XII

AOV FOR RUMEN pH

Source	df	MS					
		pH-0	pH-1/2	pH-1	pH-2	pH-4	pH-8
Total	15						
Period	3	0.040	0.024	0.026	0.025	0.056	0.034
Animal	3	0.018	0.052	0.116	0.050	0.038	0.053
Ration	3	0.018	0.009	0.051	0.255	0.276	0.015
Error	6	0.038	0.005	0.014	0.015	0.015	0.024

TABLE XII

AOV FOR *IN VITRO* GAS PRODUCTION

Source	df	MS						
		1 hr.	2 hr.	3 hr.	4 hr.	5 hr.	6 hr.	Ttl.
Total	7							
Run	1	87.12	1.53	6.85	0.98	0.45	1.13	143.65
Proc. Met.	3	112.94	36.40	21.16	8.46	5.47	2.82	682.16
Run × Proc.	3	14.64	0.17	0.14	1.30	0.94	0.73	20.67

TABLE XIV

AOV FOR *IN VITRO* DMD

Source	df	MS			
		3 hr.	6 hr.	9 hr.	12 hr.
Total	19				
Proc. Met.	3	519.15	306.06	438.45	432.94
Within Proc.	16	5.35	9.10	13.36	13.17

VITA

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