FACTORS AFFECTING STARCH DAMAGE DURING THE STEAM FLAKING OF SORGHUM GRAIN

by

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I dedicate this work to my wife, Margaret, who has given of her time and energy in so many phases of the project and to my parents, Mr. and Mrs. Bill Roth, for their encouragement.

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Chapter 1

INTRODUCTION

The commercial cattle feeding industry of the southwest has grown tremendously in recent years due, at least in part, to the abundant supply of cereal grains and the dry climate. In Kansas the number of cattle fattened annually tripled between 1965 and 1970.

Cereal grains are the principle energy source in modern fattening rations with grain sorghum or milo most common. It has long been known that sorghum must be processed for efficient utilization by cattle. Until about 1965, dry rolling and coarse grinding were the common processing methods. Hale and Taylor (1965) and Husted (1966) reported that sorghum grain is covered by a hard outer layer which resists digestion and must be broken if the grain is to be efficiently utilized.

Researchers at the University of Arizona pioneered work in developing the steam processing and flaking method of preparing milo. They demonstrated improved efficiency and digestibility when the grain was flaked as compared to dry rolled (Hale et al., 1964, 1965 and 1966).

Other workers have attempted to use modifications of the Arizona system and have not always been successful (Garrett, Lofgreen and Hull, 1968; Garrett, 1968).

Frederick (1968) reported that a combination of heat, moisture and pressure during the steam flaking process increased the susceptibility of the milo starch to enzymatic attack.

Although production techniques have not been standardized and quality control not well defined, steam flaking has rapidly become the most accepted method of processing grain for commercial cattle feeding.

The improved efficiency from steam flaking milo is due largely to improved digestibility of the NFE or starch fraction. During flaking, the starch

molecule undergoes partial gelatinization or rupturing. These gelatinized molecules are more susceptible to enzymatic degradation.

This research was initiated because of a need for more work to determine the individual effect of flake flatness, moisture and cooking time on starch gelatinization.

Chapter II

REVIEW OF LITERATURE

Feedlot Performance

The development of sophisticated methods of grain processing has been a gradual process in which animal performance pointed the direction to further improvement in cereal utilization.

Phillipson (1952) fed flaked corn to lambs and noted a narrowing of the normal acetate:propionate ratio and an increase in the efficiency of utilization.

Preston, Brewer and Pfander (1961) noted that the sharp rise in blood urea-N characteristic or urea and casein could be reduced by the addition of corn starch. Other sources of carbohydrate had little effect, indicating a difference in the rate of utilization of various carbohydrates.

Steam rolled and dry rolled barley were studied by Thomas and Meyers (1961) in high concentrate steer finishing rations. In trial I, there was a slight improvement in feed efficiency for the steam rolled treatment (9.24 vs 9.36). In trial II, the steam rolled barley resulted in a higher daily gain (2.60 vs 2.30).

Hentages, Palmer and Carpenter (1961) used ground, cracked, steam rolled and ground steam pelleted corn to study the effect of physical form on cattle response. The steam rolled product was described as a flake. Consumption was reduced and efficiency increased by both heat processes. Feed/lb gain ranged from 7.5 for the steam rolled to 9.0 for the cracked corn. An increase in the percentage propionic acid of the total VFA's 8 hours post feeding was also observed for the steam flaked corn treatment.

An apparent decreased palatability but increased efficiency was observed for flaked corn by Newland, Mages, Branaman and Blakeslee (1961). The flaked

corn was prepared by fine grinding, cooking at 250°F for 30 minutes, rolling into a thin ribbon and drying, at which point the ribbon broke into flakes. Other treatments included ground, pelleted and flaked-pelleted-crumbled corn. The ruminal acetate:propionate ratio was narrowed significantly by processing.

Hale et al. (1964) described a method for steam processing milo which increased its value by $7.20 per ton over dry rolling. The process entailed steaming at atmospheric pressure for 20 minutes at 205 to 210°F and then rolling. Low pressure (20 psi at steam generator) steam was used and the product moisture was 18 to 19% after rolling. In feeding trials the steam processed milo resulted in more rapid weight gain (3.04 vs 2.88) and better conversion (708 vs 758) than dry rolled sorghum grain.

Ground corn steam cooked at 180°F for 5 minutes then extruded and flaked at the die decreased intake on three lamb feeding trials (Jordon, 1965). The corn reached a temperature of 250°F in the barrel of the extruder but was only exposed to this temperature about 10 seconds. The increased efficiency was too slight to offset the cost of processing the corn. Similar findings have been reported by Mudd and Perry (1968).

Hale et al. (1965) observed increased intake, gain and improved efficiency when flaked milo was compared to dry rolled. Steam flaking barley increased both intake and gain but did not alter feed conversion. The grains were steamed in an open chamber at 205 to 210°F and rolled through a 10x20 Davis roller mill with 14 cut rolls. The workers reported that difficulty in rolling was minimal when rolls were worn nearly smooth and that milo must be at least 16% moisture to roll satisfactorily. Boiler pressure was 20 psi and grain normally entered the roller at 18 to 20% moisture. Steaming for 3 to 5 minutes was insufficient to improve the steam processed grain over dry rolling. Hale (1968) again reported no improvement in feed efficiency from steam flaking barley, 722 vs

735 lbs/cwt gain. However; Garrett, Lofgreen and Hull (1967) have demonstrated a significant improvement in efficiency of utilization for barley which was steam processed and flaked.

The capacity of the roller mill when making a good flake has been reported to be 1/3 to 1/2 that of dry rolling. A good flake was described as one which was rolled so as to be "flat" in appearance (Hale and Taylor, 1965).

Increased daily gain and feed efficiency was reported for pressure processed as compared to atmospheric steamed sorghum (Garrett, Lofgreen and Hull, 1965). They reported no difference in daily gain or efficiency when comparing milo steamed 8 minutes at atmospheric pressure and flaked to dry rolled milo.

Sorghum grain processed at 60 psi and flaked depressed consumption when fed to cattle (Garrett, Lofgreen and Hull, 1966).

Hale et al. (1966) used a Moorspeed roller mill with roll spacing of 0.003 inches to produce a poor and an excellent milo flake. The grain entered the rolls at 20% moisture after 20 minutes steaming at atmospheric pressure. The 25 lbs/bu excellent flake was produced by feeding the 18x30 roller mill at 3 tons/hour. The poor flake (36.4 lbs/bu air dry) was produced by tripling the feed rate. Rate of gain was similar for both flakes, but cattle receiving the excellent flake required 81 lbs less feed/cwt gain.

Replacing 40% of the cracked milo in an 84% concentrate ration with popped milo resulted in similar gains, but a 16% improvement in efficiency (Ellis and Carpenter, 1966).

Menzies et al. (1966) finished lambs on a 45% sorghum ration in which 0, 33, 66 and 100% of the dry ground milo was replaced by extruded milo. A fifth treatment consisted of 100% of the grain steam rolled. Daily feed consumption decreased as the percent extruded milo in the ration increased and the treatment

with all extruded milo exhibited the lowest gain and poorest feed efficiency. The ration containing 2/3 of the grain as extruded was most efficient, while the steam rolled milo treatment group gained the fastest.

Hentages et al. (1966); Matsushima, Sprague and Johnson (1966); and Matsushima and Montgomery (1967) compared flaked and dry rolled corn and found similar rates of gain, but improved feed efficiency for the flaked corn. Similar results were obtained with milo (Brethour and Ely, 1969).

Milo processed by steam flaking, dry rolling, fine grinding, reconstituting and rolling or by reconstituting and grinding was compared in cattle finishing rations by Newson et al. (1967). Both feed efficiency and rate of gain were superior for the flaked sorghum treatment.

Matsushima and Stenquist (1967) compared ensiled high moisture corn rolled just prior to feeding to flaked corn processed by atmospheric steaming 12 minutes and rolled to 0.08 cm thickness. Feed efficiencies were similar, but cattle on the flaked corn consumed slightly more and gained faster.

Popped, flaked and cracked milo were compared by Dunbar, Ellis and Cude (1967). No differences in gain or conversion were of statistical significance, but feed intake was significantly depressed by flaking.

Drake et al. (1967) fed graded levels of extruded sorghum in cattle finishing rations. The ration containing the highest level of extruded milo was most efficient, but the trend was not consistent and there was little difference in rate of gain.

Garrett (1968) processed milo and wheat by atmospheric steaming 8 minutes and rolling, pressure processing 1.5 minutes and 50 psi and rolling, pressure processing 1.5 minutes at 80 psi and rolling, and dry air expansion "popping". Cattle receiving pressure processed wheat consumed significantly less than

other wheat treatments. Gain was depressed and approached significance. There were no differences among milo treatments in performance or efficiency, VFA's or acetate:propionate ratios. This is in contrast with other workers (Adame, Riggs and Sorenson, 1968) who reported depressed intake and gain and a lowering of acetate:propionate ratios from 1.82 for dry rolled milo, down to 0.88 for normal run popped sorghum.

Garrett, Lofgreen and Hull (1968) and Garrett (1969) reported that feed efficiency was improved when intake of pressure processed milo was not depressed sufficiently to retard performance.

Flaked grain weighing 35 lbs/bu was compared to milo weighing 21 lbs/bu where the milo had been steam processed at atmospheric pressure for 6 and 141 minutes, respectively (Lofgreen, Mendel and McIlroy, 1968). The steers fed the rolled grain ate and gained significantly more than those fed the flat flake, although there was little difference in conversion (5.27 vs 5.34). The roller mill capacity of 3.6 tons/hour for the rolled product was reduced to 0.75 ton/hour when producing the flat flake.

A comparative slaughter technique was used to determine the energy value of sorghum grain processed by steam flaking, micronizing, dry grinding and reconstituting (Eulaly et al., 1966). The all-concentrate ration was fed 168 days during which time the cattle fed micronized grain gained faster than those on other treatments. The cattle on steam flaked milo were a close second and were followed by reconstituted and dry ground. Feed conversion was most desirable with steam flaked grain, equal for micronizing and reconstituting and poorest for dry rolled process. Net energy for production was higher for the micronized grain than the other processes, while steam flaked sorghum was given the highest net energy for maintenance value.

Schuh et al. (1969), in two trials with dairy calves, found that flaking milo significantly improved efficiency by 9% and 11% over steam rolling. Steam flaking barley resulted in a small, nonsignificant improvement in efficiency over steam rolling. There were no differences in rate of gain among treatments.

Riggs (1970), reviewing literature on sorghum grain processing, reported that micronization depressed intake; but improved efficiency and digestibility as compared to dry ground milo. In commercial feedlot studies milo could be popped about 26¢/ton cheaper than flaking. Net energy values of processed sorghum grain were dry ground, 73; reconstituted ground, 90; steam flaked, 96; and micronized, 82 Mcal/cwt. Lambs were less dependent on processing for maximal utilization of starch than cattle; probably due to increased hydrolytic capacity in the small intestine. Studies with swine indicated improved digestibility of protein and gross energy when milo was steam flaked or reconstituted, but performance differences too slight to be economical.

Arnett (1970a,c) compared methods of processing grain sorghum in both growing and finishing rations and found that steam flaking improved feed efficiency over dry rolling; 878 vs 1010 during the growing phase and 840 to 922 during finishing. Arnett (1970d) also investigated the effect of pressure when extruding milo for cattle. Increasing pressure decreased feed required per unit gain up to a point where consumption dropped and efficiency decreased.

Steam rolling and pressure processing were compared by Schuh, Hale and Theurer (1970) using young dairy calves. Milo was processed 25 minutes at atmospheric pressure, 102°C flaked or at 3.5 kg/cm^2, rolled. No differences were observed in either gain or conversion.

Garrett (1970) compared energy utilization of milo processed 8 minutes at atmospheric pressure and rolled to milo processed 1.5 minutes at 50 psi and rolled.

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No differences were observed in daily gains of the finishing steers, but feed required per unit of empty body weight gain significantly favored pressure processing. NE_g values were calculated to be 69 Mcals/cwt and 51 Mcals/cwt for pressure processed and atmospheric processed milo, respectively.

Lofgreen (1970) compared ground wheat, steam flaked wheat and steam flaked milo for finishing cattle. All treatments were equal for both efficiency and gain. Wheat was flaked to 28 lbs/bu; milo flakes weighed 27 lbs/bu. Milo was steamed 30 minutes; wheat 12 to 15 minutes.

Dry heat processing or "micronizing" was compared to steam flaking as methods of preparing sorghum grain in cattle finishing rations (Schake et al., 1970). Rate of gain favored micronizing (2.62 vs 2.50 lbs/day), while conversion was more efficient when milo was flaked (840 vs 860 lbs/cwt gain). Other characteristics of the flaked and micronized milo were test weights, 22.8 and 38.4; starch gelatinization, 69.2 and 41.6% and moisture content, 19.6 and 8.5%. Cost of processing was reported to be $1.81/ton with flaking and $1.32/ton for micronizing.

Lofgreen and Dunbar (1970) evaluated milo processing by a steam pressure method of popping, "exploding", or steaming 30 minutes at atmospheric pressure and flaked to 36, 28 or 20 lbs/bu. All treatments were similar in promoting weight gain; however, popping and flaking to either 28 or 20 lbs/bu all significantly improved feed conversion. There was no difference between milo flaked to 28 or 20 lbs/bu. Exploding was accomplished by holding the milo for 15 to 20 seconds at a steam pressure of 225 to 250 psi (392 to 401°F) then releasing through a 3"x.25" orifice. Popping was nearly 100%.

Lofgreen (1971) found that steam flaked corn was utilized more efficiently by steers than either whole or dry rolled corn. Rate of gain was similar among treatments. [illegible] (1971).

Yauk, Drake and Schalles (1971) compared sorghum grain processed by steam flaking, popping, reconstituting and dry rolling. Gains were similar with cattle receiving flakes gaining 2.72 lbs/day as compared to 2.46 for dry rolled. All three processing methods significantly improved efficiency over dry rolling. Flaking resulted in greatest efficiency as compared to dry rolling, 5.49 vs 7.85 lbs/lb gain. The steam flaked milo was processed 40 minutes at 210°F and rolled to a hot test weight of 23.5 lbs/bu.

Arnett (1971a,c) found that flaking and extruding milo resulted in better feed utilization than either dry rolling or reconstituting. Extruding the total blended ration improved feed efficiency 10% over extruding only the sorghum and then blending the ration (1971d). Wheat was utilized as efficiently when dry rolled as when flaked, extruded or reconstituted; but all were much superior to feeding whole wheat (1971f).

Dry rolling was equal in promoting gain and efficiency to poorly flaked milo for dairy calves (Morrill, 1971). However, calves receiving extruded milo exhibited superior gain and conversion, indicating that heat processing could be effective.

Ames (1971) compared popped, flaked and dry ground milo in finishing lamb rations. A fourth treatment evaluated preference by allowing free access to all three processes. Both flaking and popping improved gain and efficiency over dry grinding. Lambs in the preference treatment consumed 70% popped, 18.5% ground and 11.5% flaked milo. This group also had the most rapid gain and were most efficient.

Bolson, Cox and Drake (1972) used steam flaked milo as a control treatment when studying organic acid preservation of reconstituted milo stored in concrete silos, metal bins or oxygen-limited storage. Cattle receiving flaked milo ate significantly less than other treatments and gained slightly less than those

cattle receiving the acid-preserved or oxygen-limited stored reconstituted grain. However; gain for the flaked milo treatment was 2.98 lbs/day and was more efficient, even though the cattle were fed to a final weight of 1120 lbs.

In Vivo Digestibility

Arnett and Bradley (1961) found the nitrogen free extract (NFE) portion of flaked corn to be significantly more digestible than that of ground or pelleted corn.

Feeding an all-barley ration raised the percent propionic acid of the rumen volatile fatty acids and resulted in more efficient feed conversion, but there were no differences in efficiency or digestibility between dry rolling or steam rolling the barley (Hayer, Taylor and Hubert, 1961 and Parrott et al., 1967).

Woods and Luther (1962) found a narrowing of the acetate:propionate ratio from pelleting a complete ration used for finishing lambs.

Saba et al.(1964) reported the digestibility of the NFE fraction of barley to be 90.8% as compared to the 79.3% observed for milo. This indicated that the difference in utilization of the grains was due to a lack of digestibility of the milo starch. Work by Hale et al. (1964) was in agreement, but also noted that cooking the milo raised the digestibility of the NFE fraction from 70.4% to 76.3%.

Kenting et al. (1965) also noted increased digestibility of the NFE portion of milo by cooking a mixture of 1 part milo to 2 parts water at 180°F for 9 hours, but noted a significant decrease in the digestibility of the protein.

Hale et al. (1965) reported that steam processing and flaking milo significantly increased the digestibility of dry matter, nitrogen free extract, and gross energy as compared to dry rolling the milo. TDN was increased, but the digestibility of ether extract was depressed. Protein digestibility was

unaltered. The TDN of the flaked milo was 79%, while that of the dry rolled milo was 71%.

Post-ruminal digestion becomes increasingly important as dietary starch intake is increased. More starch may reach the small intestine than can be digested when the ration is high in concentrates (Karr, Little and Mitchell, 1966).

Husted, Hale and Theurer (1966) conducted digestibility studies with milo processed the following four ways: (1) dry rolled through a 10x20 Davis roller mill, (2) steam processed 20 minutes and flaked through the 10x20 roller mill with no tolerance on the rolls, (3) steam processed 20 minutes and passed through a decorticator which cut the kernel into six to eight pieces without applying physical pressure and (4) soaked in water 16 hours and cut through the decorticator at about 36% moisture. They found that the digestibility of dry matter, NFE and gross energy were significantly improved by steam flaking. Soaking and cutting significantly improved protein digestibility and TDN.

Steam flaking or pressure cooking and flaking resulted in the lowered digestibility of ether extract; but significantly improved digestion of dry matter, nitrogen free extract, and gross energy as compared to dry rolling or fine grinding. Pressure cooking at 40 psi tended to lower protein digestibility (Mehen et al., 1966).

Hale et al. (1966) and Husted et al. (1968) have reported that steam flaked sorghum grain was superior to dry rolled in digestibility of NFE and TDN.

An upward trend in dry matter digestibility from pressure processing milo 1.5 minutes, 50 psi; or 1.5 minutes, 80 psi; over processing 8 minutes at atmospheric pressure prior to rolling was reported by Carrett (1968).

Johnson, Matsushima and Knox (1968) flaked corn by atmospheric steaming 12 minutes at 93°C, then rolling at near zero roll tolerance at a rate of 21 kg/min.

The moisture content was increased about 4% during steam processing. Digestibility was improved 4 to 6% by flaking and energy retention was increased by 6 to 10%. The rate of passage through the gastrointestinal tract was 24% more rapid for the flaked corn.

Dry air popping of sorghum grain at 310°F significantly increased the digestibility of dry matter, organic matter, NFE and nonprotein organic matter over the original grain (Adame, Riggs and Sorenson, 1968; Riggs et al., 1970).

Buchanan, Totusek and Tillman (1968) reported that sheep and cattle do not differ in their digestibility of steam processed or reconstituted milo. Nonprotein organic matter digestibility was improved by flaking over grinding, while protein digestibility tended to be depressed.

McNeill, Potter and Riggs (1969) reported that ruminal digestion of milo starch was more complete when steam flaked or reconstituted than when dry ground or micronized.

Garrett (1969) compared the energy utilization of milo rations in which the grain had been either processed 8 minutes at atmospheric pressure and rolled or 1.5 minutes at 5.6 kg/cm^2 and rolled. Rations were utilized equally for maintenance, but the pressure processed sorghum was not efficient for production.

Milo was processed by dry rolling, or steaming 1.5 minutes at 30, 50 or 70 psi before rolling. The digestibility of dry matter, gross energy and protein trended upward as processing pressure was increased (Figroid et al., 1969).

Holmes, Drennan and Garrett (1970) observed that 89.3% of the starch, in a ration containing milo processed 8 minutes at atmospheric pressure and rolled, was digested in the rumen as compared to 94.5% for a ration in which the milo was processed 1.5 minutes at 3.5 kg/cm^2. Overall starch utilization was 97.3 and 97.6% which indicates nearly complete post-ruminal compensation. In vitro incubation rates indicated that the rumen microflora was adapted to the readily fermentable diet within 5 weeks.

Sorghum grain processed by grinding, steam flaking, reconstituting and micronizing was evaluated by McNeill, Potter and Riggs (1970). Both ruminal and total starch utilization were greatest for steers fed steam flaked or reconstituted milo. Post-ruminal starch digestion was insufficient to overcome limited ruminal utilization of ground or micronized sorghum. They indicated that the starch granule must be released from its protein matrix to be efficiently utilized. The starch energy of sorghum grain is enclosed in small cells by low quality, poorly soluable protein. When ruptured, the starch and protein become available. Ruminal utilization of both starch and protein were significantly improved by reconstituting and steam flaking. Conversion of feed protein to microbial protein was evaluated using lysine and leucine ratios and this conversion was enhanced by both flaking and reconstituting. These results agree with Potter, McNeill and Riggs (1970).

Yauk, Drake and Schalles (1971) processed sorghum grain by steam flaking, reconstituting, dry air popping and dry rolling. NFE digestibility was significantly higher for flaked milo than other treatments. NFE digestibility of the popped grain was significantly higher than that of the reconstituted grain, which was significantly higher than dry rolled. The TDN of the flaked milo was also significantly higher than all other treatments.

McLaren and Matsushima (1971) fed extruded corn which was 10, 45 and 90% gelatinized and found more starch digested in the rumen with the 45 and 90% levels than with the 10%. Virtually all of the starch which escaped rumen fermentation was digested in the small intestine.

Hale (1971), in a grain processing review, noted that quality control is essential in steam processing and flaking systems. He stated that the depressed starch digestibility associated with poor flakes may be due to protein

denaturation, and that the full impact of grain processing must be evaluated by studying the utilization of the grain fractions in the various segments of the alimentary tract.

Chemical and Physical

Salsbury, Hoerer and Lucike (1961) reported that application of moist heat to starch causes hydration and the hydrated starch was more rapidly digested by rumen microorganisms. These findings are in agreement with Frederick, Theurer and Hale (1968).

The effect of flake integrity on animal performance has been evaluated (Hale et al., 1968). Rations containing 80% steam flaked milo were fed with flakes intact or reground prior to feeding. Grinding the flakes reduced gain and efficiency and increased feed cost/cwt gain by $1.92. The same effect has been reported with wheat flakes (Hale et al., 1970) and extruded milo (Arnett, 1971b).

Johnson, Matsushima and Knox (1969) reported that flaking corn resulted in partial starch granule birefringence loss, increased water uptake, decreased specific gravity of soaked particles and larger particles. During sieve analysis 79.6% of the flaked corn was retained on a 5 mm screen as compared to only 16.3% of the cracked corn. The flaked corn has 40% starch granule gelatinization measured by loss of birefringence.

Pharr (1968) defined starch gelatinization as "The rupturing of the starch molecule making it more susceptible to enzymatic degradation". He reported that milo starch gelatinization of 30 to 50% is a practical level at which mill capacity will be adequate and satisfactory animal performance is expected.

Reeve and Walker (1969) reported differences in the microscopic structure of popped cereals. Barley and wheat swelled only slightly when popped, and starch gelatinization (loss of birefringence) was not extensive. Sorghum and

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Reeve and Walker (1969) reported differences in the microscopic structure of popped cereals. Barley and wheat swelled only slightly when popped and starch gelatinization (loss of birefringence) was not extensive. Sorghum and popcorn were highly gelatinized during popping and the kernel swelling was very pronounced. Dent corn was gelatinized to nearly the extent of sorghum or popcorn, but was much less swollen. Sorghum starch granules near the aleurone or in deep endosperm near the scutellum were poorly gelatinized. Horny endosperm was the major constituent of the expended portion of popped kernels where the cells were not ruptured. This may be due to differences in endosperm types (Cox, McMasters, Hubert, 1944; Zuber, 1965). The percent popped kernels was related to the moisture content of the grain. The highest yield of popped milo occurred at a moisture of 18 to 20%. This relationship between moisture content and starch gelatinization has been noted by other workers (Walker, Rockwell, Kohler, 1970; Walker, 1970; Riggs, Sorenson, Hobgood, 1970; Pfost, 1971; Seib, 1971). Animal performance apparently is not retarded until ration moisture exceeds about 35% (Arnett, 1970b; Brethour and Duitsman, 1970; Arnett, 1971e).

Using <u>in vitro</u> estimations of digestibility; McGinty, Riggs and Kunkel (1969) noted differences among sorghum varieties with those varieties having the least nitrogen in the pericarp yielding the highest gas production. Tanic acid added to the fermentation media depressed <u>in vitro</u> gas production. Differences

in the response of sorghum types to processing have also been noted by Hinders and Eng (1970, 1971), Hale et al. (1970) and Seib (1971).

Walker, Rockwell and Kohler (1970) reported that a temperature of 230°C or higher was satisfactory for popping grain and that exposure time required was about 30 seconds at 246°C. Wheat, barley and dent corn swelled to about 1 1/2 to 2 times their original volume when popped, whereas individual kernels of red or white sorghum expanded to as much as 9 times their original volume. The in vitro digestibility appeared to be related to the percent of fully expanded milo.

Walker (1970) reported that some starch gelatinization occurred during the popping process due to steam formation within the cells from the vaporization of intracellular grain moisture. The moisture level of the grain before popping may be modified as a quality control procedure.

Steam flaked milo weighing 22.8 lbs/bu was reported to be 69.2% gelatinized while micronized sorghum was said to be 47.6%. The majority of particles from both processes fell into the catagory of 0.4 to 0.2 cm, but the steam flaked product had less fines (Schake et al., 1970).

McNeill, Potter and Riggs (1970) reported that starch granules of steam flaked and micronized sorghum grain were completely gelatinized and extensively swollen, and that merely disrupting the substructure of the starch is probably sufficient to free the granule from the protein matrix.

Seib (1971) reported that when heating sorghum starch in a water suspension there is a gradual swelling until a critical temperature is reached (68 to 78°C) when granules begin a rapid, irreversible swelling accompanied by loss of birefringence, increased transparency and a change in the characteristic X-ray diffraction pattern. These changes occur with gelatinization. He defined gelatinization as "the irreversible rupture of the native secondary bond forces

in the crystaline region of a starch granule" thus, loss of birefringence by microscopic examination was said to be the most sensitive and reproducable method of measurement.

Particle size of sorghum grain ground after reconstituting was significantly smaller than when the grain was ground prior to reconstituting. Feed efficiency was significantly improved for the treatments having the smaller particle size (Berry and Riggs, 1971).

In Vitro Evaluation

Trei, Hale and Theurer (1966) resuspended rumen microorganisms in artificial saliva and used this as the inoculum for an in vitro gas production system. The substrate consisted of 2 gm of dry grain ground through a 20 mesh screen. The mixture was incubated 3 hours and gas production was correlated with dry matter disappearance (r = .95). Gas production increased with flake flatness until about 30 to 40% gelatinization was reached, after which gas production did not further increase.

An in vitro system using porcine pancreatin as the inoculum has been described by Osman, Theurer and Hale (1966). Incubation was for 30 minutes at 50°C and reducing sugars (expressed as maltose) were determined by colorimetric techniques. Pressure cooking milo at 20 or 40 psi lowered maltose values as compared to untreated grain, while cooking at 60 or 80 psi increased maltose yield by 37 and 78%. Test weight of the flaked grain appeared to provide a useful means of maintaining a desirable product during the steam flaking process.

Analysis of in vitro fermentation products showed increasing total volatile fatty acid (VFA) and narrowing acetate:propionate ratio as flakes were made flatter. Steaming without flaking lowered VFA production (Theurer, Trei and Hale, 1966).

Other workers have used rumen fluid inoculum and measured gas production or dry matter disappearance to evaluate processed grains. There is general agreement in trends; but rumen fluid is highly variable in microbial concentration with time within an animal, between animals and between doner animal maintenance rations (McGinty, Riggs and Kunkel, 1969; Neuhaus and Totusek, 1969; Trei, Hale and Theurer, 1970).

Walker, Rockwell and Kohler (1970) used an *in vitro* system in which diastase was incubated with dry grain after grinding through a 20 mesh screen in a Wiley mill. After 24 hours, values were reported in mg Glucose/gm dry sample as follows: pressure cooked flaked, 508; atmospheric steamed and flaked, 377; pressure cooked whole, 207; popped, 199 and raw milo, 50.

Differences between sorghum grain types in starch degradation from pressure cooking or micronizing have been reported (Hinders and Eng, 1970). Variables cited included the structure of the starch granule and protein matrix. Evaluation of starch degradation was by *in vitro* gas production where gas was produced by yeast hydrolysis of Glucose released by the action of amyloglucocidate on starch. This system has also been shown to be significantly correlated with starch gelatinization as measured by loss of birefringence ($r = .87$)(Hinders and Eng, 1971). Albin and Sherrod (1971) found this *in vitro* system highly correlated with ration digestible energy *in vivo*.

Other workers have also used this system successfully to evaluate the effect of grain processing (Schake *et al.*, 1970; McNeill, Potter and Riggs, 1970). Berry and Riggs (1971) have shown a relationship between particle size and *in vitro* gas yield.

Yauk, Drake and Schalles (1971) reported *in vitro* work using maltose production from the action of beta-amylase on processed sorghum grain. Gelatinization was determined by comparing maltose yield to a standard extruded milo. Sorghum

gelatinization from processing was dry rolled, 12%; steamed unflaked, 8%; flaked 24 lbs/bu, 36%; flaked 22 lbs/bu, 46%; popped, 62% and reconstituted, 10%. Pfost (1971) reported that the beta-amylase method would evaluate starch damage when microscopic methods were unable to pick up the effect of additional processing. Pfost, Penner and Roth (1971, unpublished) found the beta-amylase method to be correlated with test weight of the flaked milo ($r = -.95$). They also used a Steinlite moisture tester to compare di-electric constants of intact, air dry flakes. There was a high correlation between maltose yield and Steinlite reading ($r = -.96$) and between test weight and Steinlite reading ($r = .99$). Flake thickness was also measured with a micrometer and the average of ten readings correlated with test weight ($r = .85$).

Seib (1971) reported that the best method for estimating gelatinization in processed cereals is to use an enzyme susceptibility method and estimate gelatinization in the initial, accelerated portion of the curve.

Mercier (1971) evaluated a number of grain processing methods using <u>in vitro</u> digestibility and starch alternation. Steam flaking appeared to be the best method for processing both milo and corn.

THIS BOOK CONTAINS NUMEROUS PAGES WITH MULTIPLE PENCIL AND/OR PEN MARKS THROUGHOUT THE TEXT.

THIS IS THE BEST IMAGE AVAILABLE.

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Chapter III

FACTORS AFFECTING STARCH DAMAGE DURING THE STEAM FLAKING OR SORGHUM GRAIN

The steam processing and flaking of sorghum grain for feed use has become widely accepted. Steam flaking milo can improve feed conversion and digestibility as compared to dry rolling or coarse grinding (Hale et al., 1964; 1965 a,b,c; 1966, Husted, Hale and Theurer, 1966; Mehen et al., 1966; Husted et al., 1968; Buchanan-Smith, Totusek and Tillman 1968; McNeill, Potter and Riggs, 1969; Brethour and Ely, 1969; Arnett, 1970a,b; Yauk, Drake and Schalles, 1971 and Arnett, 1971). It has also been shown that the improvement in utilization obtained from steam flaking is at least equal to that obtained by reconstituting or popping (Newson et al., 1967; Garrett, 1968; Adame, Riggs and Sorenson, 1968; Eudaly and Riggs, 1969; McNeill et al., 1969, 1970; Schake et al., 1970; Lofgreen and Dunbar, 1970; Yauk et al., 1971; Bolson, Cox and Drake, 1972).

Hale et al. (1966) and Lofgreen and Dunbar (1970) have shown that the degree of flake flatness was a critical factor in obtaining satisfactory animal performance. Frederick, Theurer and Hale (1968) reported that a combination of heat, moisture and pressure were involved during the steam flaking process in increasing the susceptibility of the milo starch to enzymatic attack.

A relationship between moisture content of grain and the amount of starch gelatinization occurring during processing has been reported (Walker et al., 1970; Riggs, Sorenson and Hobgood, 1970; Pfost, 1971; and Seib, 1971).

This study was initiated in an attempt to individually evaluate the importance of flake flatness, cooking time and moisture content in regard to the amount of starch ruptured (gelatinization) during the process. Enzymatic susceptibility was used to evaluate starch rupturing. Berry and Riggs (1971) have shown that processing can significantly affect the grinding properties of milo.

Since surface area is an important factor in enzymatic reactions, an attempt was made to use the methods of Headly and Pfost (1970) to evaluate grinding differences due to processing and to correct for surface area in the enzymatic determination.

Experimental Procedures

The Steam Flaking Process

The grain used throughout this study was "elevator run" No. 2 red sorghum which was accumulated in a 200-ton hoppered steel bin. The grain was harvested in September and October (1971) and the flaked grain samples taken through April. The moisture content of the grain averaged 15% and the test weight 57 lbs/bu. Prior to flaking, the grain was passed through a 17/64" round hole screen and over a 4/64" round hole screen to remove foreign objects. Hulls and other chaffy material were removed by dropping the grain through an upward moving air stream. The grain was stored in bins above the steam flaking equipment where it remained until use.

Steam processing was done in a Ross model 960 (96 cu ft) stainless steel steam chamber with a capacity of about 4300 lbs. Eight steaming tubes ran through the steam chamber at five different levels. The steam was supplied by a 40 hp Superior scotch marine boiler operated at 70 to 90 psi. The steam was released to atmospheric pressure within the steaming chamber and the temperature of the grain elevated to 210°F.

The rate of grain discharge from the steam chamber to the flaking rolls was regulated by a feeder roll and adjustable feed gate. The Ross Heavy Duty roller mill with 18" diameter x 24" long rolls, corrugated with 24 Stevens cuts/inch and powered by a 40 hp electric motor was immediately below the steam chamber.

The hot, moist grain passed between the flaking rolls which were set at zero tolerance. Normally this station produces milo flakes weighing 24 lbs/bu.

Flake Test Weight

The bulk density or test weight of flaked grains is commonly used as a quality control parameter. There may be much variation between the test weight of wet, fresh flakes and air-dry flakes. Unfortunately, much of the literature is vague as to the method of measuring test weight.

In this study, test weight was determined by sampling from directly below the rolls with a long-handled ladle. The sample was taken by moving the ladle from one end of the rolls to the other at a uniform rate. The flakes were immediately poured (loosely) into a 1-pint test weight cup from a height of 3 to 4 inches. The cup was struck level with a standard maple strike-off board and test weight taken.

It would seem logical to measure flake thickness by some more direct method, such as a micrometer. This is, however, quite difficult to do accurately. Roth, Penner and Pfost (1971, unpublished) correlated flake thickness with test weight ($r = .85$). The results are illustrated in Appendix B.

Normally, flake test weight is altered during operation by altering the rate at which grain enters the rolls. It was desired to keep the amperage draw constant for this study, and to adjust test weight by altering both feed rate and roll pressure. The flaking mill was operated at 75% of the rated full-load amperage for all samples. Flakes were produced weighing from 16.5 to 47 lbs/bu. All samples were air-dried in a temperature controlled room, then ground in a Wiley mill through a 1 mm screen. Starch damage was determined by in vitro gas manometry and surface area measured by sieve analysis. Machine capacity was measured while producing some selected test weights by collecting and weighing total output of the flaking mill for 1 minute.

Retention Time

The amount of time grain is held in the steam chamber depends on the volume of the chamber and the rate of grain withdrawal. Conventional steam chests provide mass flow of the grain rather than the "funneling" which occurs in many hoppered tanks. During flaking the grain enters the steam chamber at the same rate at which it is discharged to the roller mill and the process becomes continuous.

To study the effect of retention time, the roller mill was operated routinely for an hour or so and the steaming chamber allowed to empty out. This was ample time for the flaking rolls to become heated to normal operating temperature. The steam chamber was refilled and the grain steamed as a batch. When the mass reached 210°F the mill was started and samples of both unflaked and 25 lbs/bu flakes were taken at various time intervals. Values cited for retention time were not absolute, but were relative and should be valid for comparison.

Moisture Content

A portion of the normal run grain was stored in a small bin equipped with an aeration fan and dried to 13.8% moisture. Other portions were placed in a rotating drum mixer and water added at 1, 2, 3, and 4%. The wetted grain was allowed to temper for at least 24 hours prior to flaking. Samples of the raw, steamed-unflaked and 25 lbs/bu flaked milo were prepared from the dry, normal and wetted grain treatments. All samples were taken after sufficient rolling time to allow the rolls to warm to operating temperature.

In Vitro Gas Production

An in vitro gas production system was used to estimate starch damage. Samples were air-dried and ground as described previously. One gm of raw or steam processed-unflaked grain or 0.5 gm of flaked grain was weighed into a

125 ml Erlynmeyer flask. An enzyme solution containing 1.25 gm Diazyme 160 (Miles Labs, Inc.), 15 gm Fleischmann's dry yeast and distilled water previously warmed to 39°C to make 500 ml. This solution was prepared fresh for each run and held at 39°C until use.

After adding the sample, the flasks were placed in a shaking water bath at 39°C. The water level in the bath was approximately at the 50 ml level of the flasks.

The gas entered the top of the 50 ml burets and displaced 1 N. sulfuric acid. The acid was displaced through a leveling tube attached to the bottom of the buret and to an adjustable clamp on the buret. The clamp was adjusted prior to each reading so that the level of the buret and discharge tube coincided and there was no pressure in the system. Two burets were connected to flasks containing flaked grain to give added capacity. Burets were filled and adjusted to zero prior to connecting to the fermentation flasks. A vent was provided in each connection hose so the flask stoppers could be inserted without displacing acid from the burets.

To initiate the reaction, 20 ml of the warm enzyme-yeast solution was added to each flask in the water bath; the stoppers inserted and the vents closed. A timer was set at the closing of the first vent. Vent closure and readings were done in order from burets 1 through 18. Readings were taken every 15 minutes, for 2 hours. The apparatus was adapted from Trei, Hale and Theurer (1970). A standard raw sorghum grain was included in each run.

In treatments where moisture was a variable, samples were taken in sealed glass jars and moisture determined by two-stage oven drying.

The 100 gm ground samples were sieved 5 minutes using a Ro-tap sifter [1] and Tyler sieve stack containing the no. 20, 28, 35, 48, 65, 100, 150, 200, 270

[1] Sieve analysis equipment made available through courtesy of the Dept. of Grain Science and Industry, Kansas State University, Manhattan.

and a pan. A dispersing agent (cab-o-sil) was used as well as two round-ball sieve cleaners per sieve. The dispersing agent was added by volume and was about 0.47 gm (average weight of 10 volumes of cab-o-sil). The geometric mean particle diameter, standard deviation, total surface area/gm and number of particles/gm were calculated as described by Headley and Pfost (1970).

Stepwise deletion (alpha = .05) multiple regression was used to interpret the gas yield data.

Results and Discussion

The effect of flake flatness on in vitro gas yield and sieve analysis is shown in table 1. Readings of gas production were taken every 15 minutes for 2 hours. The rate of gas release was most rapid early and decreased with time, since Diazyme 160 is an amyloglucocidase, acting on the non-reducing ends of starch chains. The number of these active sites is maximal at the initiation of the reaction and decreases as substrate is degraded to D-Glucose units. The yeast was able to convert the Glucose to gas as fast as the Glucose was released from starch. This is evident by the rate of gas production where D-Glucose alone was used as the substrate. The observed time vs gas yield relationship agrees with Walker et al. (1970) and Seib (1971), who also noted that estimation of starch damage should be made early in the incubation where substrate is not limiting. The 30-minute readings were chosen for comparison. The 30, 60 and 120-minute readings were presented in order to establish the relationship of gas yield vs time.

A sample of extruded milo was included for reference purposes. The extrusion process is normally expected to produce total gelatinization. The milo was ground through a 1/16" hammermill screen prior to extrusion. The average particle size after grinding was 361.5 microns. The grain was then extruded in a

X-25 Wenger extruder through a 3/8" die. The grain temperature reached 285°F at the die head and remained in the barrel 12 to 15 seconds. A 1-hour incubation with beta-amylase at 40°C yielded 211 gm maltose/gm sample. This sample was ground through a coffee grinder and was obviously finer than the flaked grain samples which were ground through a 1 mm screen in a Wiley mill. Among the ground flake samples there was a trend toward increasing particle size and decreasing surface area as processing severity increased. This trend must be attributed to a difference in grinding properties due to processing, as all samples were air-dried and ground in the same mill.

Retention time in the steam chest, within the limits studied, did not appear to influence gas production. According to the regression equations (table 4), increasing retention time tended to decrease the gas yield of the steamed unflaked samples; but increased gas production of the flaked samples. In either case, the regression coefficient of the retention time is small. Hale et al. (1965c) reported that retention time of 3 to 5 minutes is inadequate to improve cattle performance while Garrett, Lofgreen and Hull (1965) found no differences in gain or efficiency between dry rolled milo and milo steamed 8 minutes prior to flaking.

Increasing moisture prior to popping grain (Walker et al., 1970) and pressure cooking (Pfost, 1971) has increased in vitro enzyme susceptibility. Adding moisture prior to flaking has not been studied. In this study, increasing moisture increased gas yield as is evident from the regression equations. There was no difficulty in flaking the milo at any of the indicated moisture levels and machine capacity may have been increased (table 5).

Table 1

EFFECT OF FLAKE TEST WEIGHT ON
IN VITRO GAS YIELD AND SIEVE ANALYSIS

Test wt (lbs/bu)	Ml gas/gm Incubation time (min) 30	60	120	Particle diameter (microns)	Surface area gm (sq cm)	Ml gas/100 cm^2 (30 min)	Standard raw milo (30 min)
47.0	12.15	16.55	25.50	377	151.01	8.04	11.25
43.5	12.75	17.95	28.30	390	144.17	8.84	10.80
43.5	12.65	18.20	29.00	356	162.22	7.80	10.80
41.0	18.30	25.60	38.20	371	149.21	12.26	11.75
38.0	21.70	32.00	49.90	381	140.90	15.48	11.75
35.5	23.10	37.70	61.70	392	138.85	16.64	11.20
33.0	40.20	61.20	92.20	361	159.91	25.14	11.85
29.5	53.30	80.90	115.40	406	131.06	40.67	11.85
26.5	66.10	97.70	131.60	421	125.47	52.68	11.85
23.5	72.50	105.00	137.10	444	116.59	62.18	10.80
22.5	82.20	116.70	147.90	411	127.72	64.36	10.80
20.5	88.00	122.70	153.10	437	117.14	75.12	10.80
19.5	88.60	125.10	156.40	441	114.75	77.21	11.25
17.5	98.40	131.80	161.90	426	118.90	82.76	11.25
16.5	101.90	135.00	161.20	409	123.36	82.60	11.25
Extruded	106.50	121.90	129.10	267	203.86	52.24	11.20
D-Glucose	164.00	262.00	264.00				11.85

Table 2

EFFECT OF STEAM CHEST RETENTION TIME ON
IN VITRO GAS YIELD AND SIEVE ANALYSIS

Retention time (min)	Ml gas/gm Incubation time (min) 30	60	120	Sieve Analysis Particle diameter microns	Surface area cm^2/gm	Ml gas/100 cm^2 (30 min)	Standard milo (30 min)
Steamed-unflaked							
20	12.90	15.20	19.65	431	122.47	10.53	11.65
34	12.20	14.30	18.55	418	126.95	9.61	11.65
42	12.25	14.55	18.75	418	126.10	9.71	11.65
50	11.90	14.00	18.25	368	151.84	7.84	11.65
50	11.10	13.70	18.15	414	176.55	8.77	11.65
50	12.60	14.95	19.40	420	126.55	9.96	11.65
Flaked 25 lbs/bu							
20	67.40	98.30	133.80	416	125.46	53.72	11.65
40	70.60	102.70	138.60	411	125.43	56.29	11.65
50	71.50	103.70	138.20	423	120.69	59.24	11.65
50	72.90	105.50	141.30	399	128.69	56.53	11.65
50	72.30	105.10	142.10	402	127.16	56.78	11.65

Table 3

EFFECT OF MOISTURE CONTENT ON IN VITRO GAS YIELD AND SIEVE ANALYSIS

Treatment	Ml gas/gm Incubation time (min) 30	60	120	Particle diameter microns	Surface area/gm sq cm	Ml gas/ 100 cm^2 (30 min)	Standard raw milo (30 min)	Two-stage oven moisture
Raw grain								
Dry	14.25	16.55	21.50	392	147.28	9.68	12.5	13.8
Normal	12.75	14.00	19.60	387	147.53	8.64	12.5	14.5
+1%	12.85	15.20	19.90	387	146.31	8.78	12.5	15.9
+2%	15.65	19.35	25.80	397	148.59	10.53	13.0	19.6
+3%	14.85	18.20	24.40	410	139.23	10.66	13.0	22.1
+4%	14.55	18.15	24.25	423	129.84	11.21	13.0	21.8
Steamed-unflaked								
Dry	10.35	12.30	14.95	379	140.81	7.35	12.05	18.7
Normal	10.05	12.05	14.85	401	127.79	7.86	12.05	21.7
+1%	14.30	15.70	18.00	363	150.20	9.52	11.20	20.9
+2%	13.75	16.20	19.70	428	128.07	10.74	11.20	21.6
+3%	13.10	15.55	19.00	420	131.32	9.98	11.20	21.2
+4%	12.75	15.15	18.85	416	136.61	9.33	11.20	23.3
Flaked 25 lbs/bu								
Dry	67.2	98.9	132.9	365	140.55	47.81	12.05	16.9
Normal	65.0	95.4	129.0	392	131.65	49.37	12.05	19.3
+1%	73.6	107.1	138.0	386	136.69	53.84	12.05	18.3
+2%	65.5	98.4	136.0	428	125.07	52.37	10.45	18.3
+3%	65.7	99.7	137.8	427	127.04	51.72	10.45	20.2
+4%	67.8	103.7	141.2	415	130.87	51.81	10.45	20.9

Table 4

MULTIPLE REGRESSION EQUATIONS OF THE VARIABLE PARAMETERS

Variable	Regression Equation	R^2	Data Points
Test wt	$Y = 52.2810 - 1.4460W + 1.4717T - .0005TW^2$	.93716	270
Retention time			
Unflaked	$Y = 5.5628 - .0702R + .1507T$	.84053	108
Flaked (25 lbs/bu)	$Y = 7.2168 + .0673R + 1.3187T$	.97112	90
Moisture			
Raw grain	$Y = -3.8528 + .3359M + .2404T - .0011T^2$	.89111	108
Steamed	$Y = -7.5090 + .4630M + .2192T - .0012T^2$	.80443	108
Flaked (25 lbs/bu)	$Y = -19.0960 + 1.2653M + 1.6166T - .0069T^2$	.98217	108

where Y = ml gas/100 cm^2 surface area

W = test weight (lbs/bu)

T = incubation time (min)

R = retention time (min)

M = moisture content (%)

Table 5

EFFECT OF VARIABLES ON FLAKING MILL CAPACITY

Variable	No. Samples	Mill capacity[1] (lbs/min)
Test weight (lbs/bu)		
28	1	111.0
26	2	90.0
25	1	79.0
24	1	78.0
23.5	2	63.0
22	1	61.5
21	1	44.5
20		
Retention time (min)		
20	2	96.5
40	3	76.7
50	6	85.5
Moisture		
Dry	3	71.0
Normal	3	76.5
+1%	3	70.2
+2%	3	77.3
+3%	3	80.5
+4%	3	87.5

1 samples taken with 75% full-load amperage

Summary

An experiment was instigated to study the effect of individually varying flake flatness, retention time or moisture content when steam processing and flaking sorghum grain. An *in vitro* system was used to estimate starch damage in which gas was produced by yeast fermentation of sugars from amyloglucocidase degradation of starch.

Surface area of the incubated grain samples was estimated from sieve analysis data and gas production comparisons made on an equal area basis.

Increasing flake flatness was particularly effective in increasing gas yield, especially below 33 lbs/bu. Over the range of 16.5 to 47 lbs/bu, the average response was about 2.5 ml gas/100cm^2 area (30 minute incubation) for each 1 lb decrease in wt/bu.

Retention time at 210°F had little influence on starch damage within the range of 20 to 50 minutes. There was a small increase in gas yield with additional cooking time, but the coefficient was small and of little consequence.

Increasing the moisture content of the raw grain from 13.8 to 22.8% prior to steam processing and flaking increased both gas yield and machine capacity with no difficulty in flaking the wet grain.

Flake flatness had the most influence on starch gelatinization. Test weight of the flaked grain is apparently an accurate predictor of ranking in regard to starch damage. Moisture content of the grain prior to flaking had a lesser but notable effect. Surface area/gm tended to decrease as flake flatness increased. The magnitude of this difference appears sufficient to justify a surface area correction when using enzymatic susceptibility tests to evaluate grain processing.

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Appendix A

Preliminary Work

An enzymatic susceptibility technique utilizing beta-amylase degradation of sorghum starch was used to study the relationship between test weight and starch gelatinization of flaked sorghum grain. The percent gelatinization was obtained by comparing maltose yield of the sample grain with that of extruded milo. Samples were collected at random over a long period of time and showed considerable variation within test weight; probably due to non-uniform grain, retention time, moisture or machine load. The results are shown in table A-1. The method of comparing against extruded milo was not considered satisfactory, as the 1 hour maltose yield of extruded milo may vary from less than 200 mg to 330 mg or more due to variation in extrusion pressure or moisture content.

Table A-1

EFFECT OF FLAKE TEST WEIGHT ON STARCH GELATINIZATION

Test wt. lbs/bu	Gelatinization, %	Test wt. lbs/bu	Gelatinization %
25.0	38.70	22.5	37.56
24.0	44.53	22.5	52.53
24.0	30.30	22.0	39.01
24.0	35.12	22.0	36.84
24.0	37.84	21.0	49.33
23.5	50.47	21.0	41.60
23.0	37.46	20.0	75.05
23.0	46.72	popped milo	79.50
23.0	52.02	popped milo	73.47
22.5	42.48	flaked wheat cereal	108.19
		extruded milo	100.00

An attempt was made to utilize an <u>in vitro</u> gas production system which was built for the purpose of screening grain sorghum varieties for possible differences in digestibility. The system involved incubating 1.00 gm samples (ground through a 1 mm screen in a Wiley mill) with strained rumen fluid in

phosphate buffer in a water bath at 39°C. The doner animals were fistulated steers fed on an all-concentrate milo diet. This system appeared to offer possibilities for rapid evaluation of grain processing; however, there was some problem in the variability of rumen fluid concentration and rather large blanks due to substrate particles remaining in the filtered rumen fluid. Typical results are illustrated in table A-2.

Table A-2

IN VITRO GAS PRODUCTION EVALUATION OF GRAIN PROCESSING

Description	Incubation time (hours)			
	0.5	1.0	1.5	2.0
	ml gas/gm			
blank	3.4	6.2	8.1	10.9
unprocessed milo	6.0	11.0	16.1	21.0
steamed-unflaked	7.0	13.3	20.6	28.2
flaked milo 20 lbs/bu	7.7	14.6	23.5	32.8
flaked milo 20 lbs/bu	7.7	15.1	23.5	33.5
reconstituted milo	6.0	12.3	19.2	26.4

The in vitro system was then modified by using a commercially available amyloglucocidase (Diazyme 160) in place of rumen fluid. Yeast was added to convert the Glucose to carbon dioxide. This system appeared to be much better adapted to evaluate the effects of grain processing. A shaker water bath replaced the conventional water bath and helped to solve the problem of substrate settling. Results obtained with this modified system are shown in table A-3. This table also presents data on the ability to duplicate a setting on the flaking mill. The indicated samples were all produced on the same day with the same lot of grain, but the machine settings were altered and later reset. These results indicated that a given test weight within a lot of grain and with equal moisture and retention time appeared to be quite similar in gas yield.

Table A-3

EVALUATION OF ABILITY TO DUPLICATE MACHINE SETTING

Sample no.	Test wt lbs/bu	Incubation time (min) 15	30	45	60	75	90	105	120
		Ml gas / gm							
69	26	8.6	17.3	25.5	32.3	38.9	44.9	50.8	56.2
69	26	9.7	19.4	28.6	36.0	43.2	49.7	56.0	61.0
76	26	9.2	17.9	26.2	33.0	39.6	45.8	51.8	57.3
76	26	9.2	18.2	26.5	33.9	40.1	46.9	53.4	59.2
71	24	10.4	21.5	31.1	40.3	49.2	56.4	63.6	69.9
71	24	10.1	20.5	29.5	37.9	46.4	53.2	60.0	66.0
75	24	10.3	21.4	30.3	37.9	45.9	52.5	58.9	64.9
75	24	10.6	21.6	30.1	38.2	46.3	52.8	59.4	65.3

At this point, it was thought to be desirable to look at enzyme and yeast concentrations in the solution. It was necessary to have a solution in which substitute availability was the only limiting factor. Since D-Glucose is the degradation product of amyloglucocidase action on starch, Glucose was used to test the effect of yeast concentration. The use of 0.60 gm yeast with 0.50 gm Glucose was adequate to provide complete fermentation in an hour. This was considered adequate since plans were to use 2 hours of incubation time. These results are illustrated in table A-4.

Table A-4

EFFECT OF YEAST CONCENTRATION ON GAS YIELD PER GRAM SUBSTRATE (D-Glucose)

Substrate (gm)	Yeast (gm)	Water (ml)	Incubation time (min) 15	30	45	60	75	90	105	120
			Ml gas / gm							
0.50	0.25	20	32.2	55.8	80.6	106.4	132.0	158.0	185.2	201.0
1.00	0.25	20	33.8	58.0	83.6	111.0	138.2	152.2	156.9	181.4
1.00	0.75	20	51.9	93.9	133.7	175.9	216.2	241.0	241.0	242.5
0.50	0.60	20	86.4	152.4	214.6	245.0	247.0	246.8	247.4	247.0

A highly fermentable flaked wheat product (Wheaties) was used to check the enzyme concentration. From the data (table A-5) it appeared that 0.04 gm Diazyme to 0.50 gm substrate was probably adequate. However, it was decided to use 0.05 gm enzyme in case more highly fermentable substrates might be encountered.

Table A-5

EFFECT OF ENZYME CONCENTRATION ON GAS YIELD PER GRAM SUBSTRATE
(Wheaties)

Substrate (gm)	Enzyme (gm)	Water (ml)	Incubation time (min)							
			15	30	45	60	75	90	105	120
			Ml gas / gm							
0.50	0.01	20	71.6	110.2	132.4	144.6	153.0	158.2	160.8	163.4
0.50	0.02	20	73.2	124.0	143.8	153.0	158.2	161.4	162.4	164.0
0.50	0.04	20	89.2	148.6	164.6	169.6	172.0	173.6		
0.50	0.05	20	90.0	154.8	169.6	173.8	175.6	177.2		

The finalized procedure is shown in Appendix D.

Appendix B

Steam Flaked Milo

Marc Roth, Maurice Penner and Dr. H. B. Pfost
(1971 unpublished.)

A brief investigation was made to study some quality control parameters of the steam flaking process. Previously cleaned whole grain sorghum (14.5% moisture) was introduced into a 96 cu ft steaming chamber. Live steam was introduced into the chamber at eight positions until the grain reached 210°F. This required about 13 minutes.

When the feeder roll was engaged the process became continuous with grain entering the steaming chamber as fast as it was discharged to the rolls. The grain temperature was maintained at 210°F. The rolls were corrugated (24 Stevens/inch) and were operated at zero tolerance.

No samples were taken during the first hour of operation so the rolls could reach normal operating temperature. Samples were taken of original, steamed-unflaked and flaked grains. Test weight was taken by collecting a sample from immediately below the rolls and from the entire width of the rolls. The percent full-load amperage draw of the motor was noted at the time of sampling.

The maltose yield was determined on oven-dried, ground samples of 1.00 gm using beta-amylase.

Flake thickness was measured on moist, room temperature flakes using a micrometer. A flake was placed in the micrometer which was then closed until slight tension was felt. The tension applied was sufficient to flatten the corrugations on the flakes.

Steinlite readings were made on flakes that had been air-dried for 3 days. Testing was made by using equal sample weights or equal sample volumes. Read- [illegible] were made on both [illegible] and 3 scale.

The oven moistures were only single stage and may be 1 to 2% low.

The results of the various measurements are illustrated in table B-1. Maltose yield trended upward as test weight decreased. The use of the Steinlite moisture tester as a quality control parameter appears to have considerable merit. The A scale reading is the most sensitive and the equal volume method appears equal to weighing the samples. Linear correlation coefficients are shown in table B-2.

Table B-1

PARAMETERS OF STEAM FLAKED MILO

Sample & Process	Test wt (lbs/bu)	Flake thickness[1] (.001 in)	Steinlite Equal wt[2] scale A	Steinlite Equal wt[2] scale B	Steinlite Equal vol[3] scale A	Steinlite Equal vol[3] scale B	Maltose (mg)	Roll motor amperage (%)	% H_2O
Raw 1	57.60						41.9		14.0
Steamed									
1	56.20						23.8		18.0
2	56.20						23.1		19.0
3	56.20						25.0		18.6
4	56.30						22.8		17.9
5	56.30						23.8		18.7
6	56.00						22.5		18.2
Flaked									
5	30.25	35.6	95.0	29.2	99.0	33.0	47.4	60-61	16.5
4	26.25	28.1	85.0	22.1	85.0	22.0	53.8	62-63	16.6
6	22.75	25.2	73.7	14.2	73.0	14.0	76.2	76-77	15.4
1	21.00	27.0	68.0	11.0	68.0	11.0	69.4	77-78	15.6
2	20.50	27.1	66.2	10.2	64.0	9.0	81.8	77-78	15.8
3	18.50	25.8	58.7	6.5	56.0	5.0	91.0	75-77	15.3
Standard Extruded							225.0		

Table B-2

LINEAR CORRELATION COEFFICIENTS BETWEEN INDICATED PARAMETERS

r =	Test wt (lbs/bu)	Flake thickness[1] (.001 in)	Steinlite Equal wt[2] Scale A	Steinlite Equal vol[3] Scale A	Maltose (mg)
-.957			X		X
-.961				X	X
-.949	X				X
.85	X	X			
.927	X		X		
.998	X			X	

1 Average of 10 flakes
2 100 gm
3 [illegible] Steinlite moisture tester Level Full

Appendix C

Sample Printout of Sieve Analysis Data

K.S.U. SIEVE ANALYSIS

Enter the weight of the material on each indicated sieve. Be sure to index GO after entering each weight.

Tyler No.	Grams
3	.00
4	.00
6	.00
8	.00
10	.00
14	.00
20	1.65
28	34.80
35	24.90
48	11.80
65	10.70
100	6.10
150	5.07
200	1.32
270	1.10
pan	.60

The geometric mean particle diameter is 417.33 microns

The geometric mean standard deviation is 1.84

Enter true specific weight for the material 1.350

The total surface area per gram is 128.52 square cm

If particles resemble cubes, index 1, if spheres, index .5238 1.0000

The number of particles per gram is 55351.59

Appendix D

In Vitro Gas Production For Evaluating Processed Grain

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Procedure

I. Apparatus.

A. Gas manometer system: 50 ml burets were used as collection vessels, displacement liquid was 1 N. surfuric acid with methyl red added to facilitate reading. Two burets were connected by use of a "T" for processed samples.

B. Thermostatic shaker water bath with rack suitable for holding 125 ml Erlynmeyer flasks.

C. Laboratory balance with 0.01 gm accuracy.

II. Preparation of Grain Samples.

A. Air dry samples.

B. Grind samples through a 1 mm screen in Wiley mill.

C. Roll samples until blended and place in sample container with spatula. Container should be moisture tight.

III. Enzyme - Yeast Solution.

A. Weigh out 1.25 gm of Diazyme 160.

B. Weigh out 15.0 gm Fleischmann's dry yeast.

C. Quantitatively transfer enzyme and yeast to 250 ml volumetric flask.

D. Add distilled water at 39°C to 250 ml. Shake vigorously after adding about 1/2 of the water.

E. Transfer to 500 ml Erlynmeyer flask, shake vigorously. Add another 250 ml 39°C distilled water and shake again.

F. Place flask containing mixed solution into 39°C water bath until use. Use as soon as possible.

IV. Operation.

A. Raise discharge tube holders to top of burets, add acid to 0 ml mark, insert stoppers of gas inlet hoses into burets, lower discharge tube clamp until menisci coincide at 0 ml.

B. Check to see that all vents are unclamped.

C. Mix enzyme-yeast solution.

D. Weigh 1.00 gm unprocessed samples or 0.50 gm processed grain into 125 ml Erlynmeyer flasks and place flasks in shaker water bath which has been preheated to 39°C. Water level in shaker bath should be at about 50 ml level of the Erlynmeyer flasks.

E. Add 20 ml of enzyme-yeast solution to each fermentation flask.

F. Insert stoppers from gas inlet tubes into fermentation flasks. Begin shaking action on water bath.

G. Close vents beginning with buret 1 and continuing in order to buret 18. Turn on laboratory timer set for 15 minutes at closing of vent 1.

H. Take readings on burets 1 through 18 every 15 minutes by first lowering discharge tube until acid levels coincide, then recording buret level at bottom of meniscus.

NOTE: When there is no interest in plotting gas yield or using statistical regression, one reading at 30 minutes may suffice to compare starch damage.

Appendix E

Raw Data

The raw data, used in the calculation of the regression equations presented in this paper, is punched on IBM cards and filed with the Department of Animal Science and Industry, Kansas State University. The cards are in six decks and are labeled as follows:

	Column 1	Column 2	Column 3	Column 4
Deck 1	Test wt (lbs/bu)	Incubation time (min)	Gas/gm (ml)	Surface area (cm^2/gm)
Deck 2 (Flaked 25 lbs/bu)	Retention time (min)	Incubation time (min)	Gas/gm (ml)	Surface area (cm^2/gm)
Deck 3 (Steamed only)	Retention time (min)	Incubation time (min)	Gas/gm (ml)	Surface area (cm^2/gm)
Deck 4 (Moisture-raw)	Moisture (%)	Incubation time (min)	Gas/gm (ml)	Surface area (cm^2/gm)
Deck 5 (Moisture-steamed)	Moisture (%)	Incubation time (min)	Gas/gm (ml)	Surface area (cm^2/gm)
Deck 6 (Moisture-flaked 25 lbs/bu)	Moisture (%)	Incubation time (min)	Gas/gm (ml)	Surface area (cm^2/gm)

FACTORS AFFECTING STARCH DAMAGE DURING THE STEAM FLAKING OF SORGHUM GRAIN

by

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FACTORS AFFECTING STARCH DAMAGE DURING THE STEAM FLAKING OF SORGHUM GRAIN

Abstract

The contribution of flake flatness, retention time and moisture content to the amount of starch damage obtained during the steam processing and flaking of sorghum grain was studied. The cleaned, whole grain was introduced into a 96 cu ft steaming chamber and the temperature elevated to 210°F with atmospheric pressure steam. The conditioned grain was then flaked through 18"x24" flaking rolls.

The effect of flake flatness was studied by simultaneously altering feed rate and roll pressure to produce flakes ranging from 16.5 to 47 lbs/bu while maintaining the amperage draw at 75% of the rated full-load for the 40 hp motor.

Retention time was studied by batch steaming the grain after a preliminary rolling period to heat the rolls. Samples were taken which had been steamed at 210°F for 20 to 50 minutes.

Original grain (14.5% moisture) was slowly dried to 13.8% or was wetted in a horizontal mixer by adding 1, 2, 3 or 4% water and tempering a day prior to flaking. Samples were taken of the raw, steamed and 25 lbs/bu flaked grain.

Samples were air-dried, ground in a Wiley mill through a 1 mm screen and re-blended. Duplicate samples of 1.00 gm raw or steamed grain or 0.50 gm flaked grain were incubated 2 hours at 39°C with 0.05 gm amyloclucocidase (Diazyme 160), 0.60 gm Fleischmann's yeast and 20.0 ml distilled water. Gas yield readings were taken every 15 minutes and converted to an equal substrate surface area basis where surface area was calculated from sieve analysis data.

The regression equation relating ml gas/100 cm^2 surface area (Y), test weight (W) and incubation time (T), was $Y = 52.2810 - 1.4460W + 1.4717T - .0005TW^2$ and illustrates that decreasing test weight increases gas yield. A

1 lb reduction in wt/bu resulted in a 2.5 ml average increase in gas yield/ 100 cm^2 at the 30 minute reading. Test weight appeared to be an excellent predictor of gas yield ranking.

Retention time (within the range of 20 to 50 minutes) did not influence gas production since the coefficient of the retention time (R) term of the regression equation was only 0.0673.

Flaking milo at elevated moisture (M) appeared to increase both starch damage and machine capacity. The flaked grain regression equation $Y = -19.096 + 1.2653M + 1.6166T - .0069T^2$, supports this conclusion.

The three variables studied, test weight; retention time; and moisture, were all of sufficient importance to be retained in their respective regression equations after using a delete option with alpha = .05 in a multiple regression program. However, test weight of the flaked grain was most useful in altering starch damage.

Sieve analysis and surface area calculations indicate that there may be considerable differences in the grinding properties of processed grains, with differences large enough to justify incorporating surface area as a correction factor when using enzymatic susceptibility to evaluate grain processing.