FEEDLOT AND *IN VITRO* STUDIES WITH PROCESSED SORGHUM AND WHEAT

By

THOMAS STEPHEN MARTIN

Bachelor of Science

Texas Tech University

Lubbock, Texas

1972

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
MASTER OF SCIENCE
December, 1973

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Thesis Approved:

Donald G. Wagner
Thesis Advisor

Richard R. Frahm

L. J. Bush

D. D. Durham
Dean of the Graduate College

ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation to Dr. D. G. Wagner, Associate Professor of Animal Science, for his guidance during the course of this study and in the preparation of this thesis. Appreciation is also extended to Dr. R. R. Frahm, Dr. L. J. Bush, Dr. A. D. Tillman, Dr. R. L. Noble and Dr. R. K. Johnson for their assistance and cooperation during the course of this study.

Grateful acknowledgement is extended to Dana Trimble, Don Croka, Mike Sharp, Larry Young, Rick Jones, Dennis Hallford, Ivan Rush, Keith Lusby and other fellow graduate students for their assistance and cooperation.

Very special recognition is extended to my wife, Linda. Without her assistance, cooperation and support, this study would not have been possible.

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CHAPTER I

INTRODUCTION

Feed costs often represent 70-80% of the total cost of feedlot gain. The type of grain in a ration depends upon price and availability as well as the feeding value. Increased production in the high plains feedlot area has frequently made the availability and price of grain sorghum and wheat very attractive to feedlot operators.

Sorghum grain has the potential nutrient and energy value to very favorably compete with any other cereal grain. However, in order to obtain maximum performance, it has been shown that some type of processing method must be imposed upon the sorghum grain particle. Various types of processing methods have been studied, and many have proven to give satisfactory improvement over dry rolling.

Recently, the price of wheat has become somewhat erratic and excessively high to permit its use as a feed grain. However, the extreme price margin that now exists has not always been the case. In past years, wheat availability has been much greater due to increased world production, and it could become a major ration component if it can compete favorably with other cereal grains in performance as well as in price. Several research stations throughout the U.S. have compared dry rolled wheat with other grains and found various advantages and disadvantages with each. However, very little work has been done concerning the effect of processing upon its feeding value.

The cost of processing and the increase in feeding value are the two major factors that will determine if any given processing technique will be economically feasible. Costs and absolute performance values will vary depending on many regional factors; but hopefully, performance differences, due to grain processing and ration formulation, will remain relatively constant.

It was the purpose of this study to determine if an improvement is obtained over dry rolling with any of the treatments imposed upon either the wheat or sorghum grain, and if so, the magnitude of the difference that could reasonally be expected. The processing methods were evaluated by feedlot performance, carcass merit, VFA production, particle size, *in vitro* dry matter disappearance, *in vitro* gas production and the degree of gelatinization.

CHAPTER II

REVIEW OF LITERATURE

Introduction

Extensive research has shown that some type of grain processing and the level of roughage in the ration significantly affects feed utilization. Grinding, dry rolling, and steam flaking have received much attention in the past 40 years; and, as technology has developed and more research results have become available, the processing of the grain component of feedlot finishing rations has become more sophisticated. Today, grinding, crushing, pelleting, and dry rolling of grains have largely been replaced by more intensive techniques that have shown improved product utilization by feeder cattle. (Albin, 1971).

Many different processing techniques are currently being examined. Some of these newer processes, such as steam flaking, steam pressure flaking, high moisture harvesting, reconstitution, chemical preservation, popping, micronizing, exploding, extruding, roasting, and head chopping have shown significant improvements in grain utilization; however, many also have shown definite limitations (Hale, 1970). Processing cost and feeding superiority will inevitably determine the economical feasibility of any given technique.

Sorghum vs Wheat

When compared to corn or barley, unprocessed milo has been shown to have a lower feeding value than its chemical composition suggests (Pope et al., 1961; Totusek et al., 1963; Hale, 1965b; Buchanan-Smith et al., 1968). Wheat, on the other hand, was found by Morrison (1957) to give a 9% better feed efficiency than corn. Brethour et al. (1966a) reported wheat to have a 9% advantage in feed efficiency over corn and a 15% advantage over milo when each was fed as the only grain component. He further reported a 17% advantage over corn and a 24% advantage over milo when wheat and corn were mixed in similar feedlot rations. Oltjen et al. (1966) reported a slightly lower value for wheat, however, than for corn.

In 1970, Brethour combined results from 18 feeding trials and found that consumption on wheat averaged about 8% less than on barley, but wheat had an advantage of about 10% in feed efficiency. When wheat was fed alone, feed intakes were reduced approximately 16% and rates of gain were 10% less compared to milo fed alone. Feed efficiencies favored wheat by about 9%. When milo and wheat were combined at different levels, decreased feed consumption, decreased gain and increased efficiency have been observed as level of wheat increased (Wagner et al., 1971; Richardson et al., 1967; Brethour, 1966; Brethour et al., 1961, 1966a).

Processing Techniques

As large numbers of cattle began to be fattened in the dry lot, one of the major areas of concern was feed utilization by the animal. Initial experimentation led to producing ground, crushed, dry rolled, soaked, and pelleted grains. Fine grinding, crushing, and dry rolling were concluded to be more efficiently utilized than whole sorghum grains, but little difference has been observed between any of the three processes (Riggs, 1958; Smith and Parrish, 1953; Baker et al., 1955; Richardson, Baker, Smith and Cox, 1955; Smith et al., 1960; Pope et al., 1962; Brethour and Duitsman, 1966b; Buchanan-Smith, Totusek and Tillman, 1968; Husted et al., 1968; Hale, 1970b). Finely ground and dry rolled milo have shown increased feed efficiency with little influence on rate of gain when compared to coarsely ground (Newson, 1968; White, 1969; Totusek, et al., 1967). Steevens (1971) and Alexander (1973) concluded that a smaller particle size increased milk production in dairy cows, indicating greater utilization. This is possibly due to increase surface area or perhaps increased ruminal "by-pass" of the smaller particle. Likewise, there has been little difference reported between dry rolled and ground wheat, although differences in particle size were not described in most tests (Baker, 1935; Darlow et al., 1945; Darlow et al., 1946). In more recent studies smaller particle sizes produced by fine grinding of wheat (Wagner et al., 1972; Wagner et al., 1971) or particle breakdown by mixing thin flaked of milo and wheat (Hale et al., 1970) have caused decreased intakes and gains, with little differences in feed efficiency. Perhaps this is due primarily to a palatability or dustiness problem. Particle size may also be less important in wheat than in sorghum.

Husted (1968) reported that ruminal starch digestion rate of milo was increased by soaking. However, Hale (1970) reported that fermentation losses while soaking the grain in warmer climates caused a significant loss in dry matter. Milo pelleting procedures, on the other hand, have been proven to increase feed efficiency, but gains have been lowered due to decreased consumption (Richardson et al., 1959; Pope et al., 1960). Pelleting wheat was deemed advantageous by increasing consumption in a study by Bris (1967). Steam rolling wheat and milo has given somewhat irratic results, but in most trials offered little if any improvement over dry rolling (Pope et al., 1960; Boren et al., 1962; Smith et al., 1960; Pope et al., 1962; Totusek and White, 1969; Cornett et al., 1971; Garrett, 1968; Garrett et al., 1966; Baker et al., 1960; Brethour, 1959b; Richards, 1940).

Steam flaking has enjoyed the most intensive use in feedlot operations. In more recent years, dry rolling has often been used as the "reference" processing method in feeding experiments. In some cases, steam flaking has been used as a basis of comparison. Various estimates of feed efficiency improvements have been given for milo. Most range from 3 to 10% with an increase in gains of about 5 to 15% when steam flaked milo is compared to ground, dry rolled, or steam rolled (Hale et al., 1966; Yauk et al., 1971; Hale 1965 a,b; Roskamp, 1965; Garrett, Lofgreen and Hull, 1968; Garrett, 1969; Garrett, 1968; Buchanan-Smith, Totusek, and Tillman 1968; Garrett et al., 1966, 1967; McElroy et al., 1967; Newson, 1968; Martin et al., 1970; Wagner et al., 1970a; Totusek and White, 1968; Hale, 1967). Garrett (1968) suggested an optimum of 8 minutes steaming at atmospheric pressure for wheat steam flaking. Cornett et al. (1971) stated that neither steam flaked nor micronized flaked processing improved wheat digestibility over dry rolling.

Milo pressure flaking was found by Hale (1970a) to have an advantage over steam flaking due to the flake being less brittle and therefore, not as subject to breaking up during mixing and handling. Holmes, Drennan, and Garrett (1970) reported that 50 p.s.i. for 1.5 minutes gave improved efficiency, but decreased feed intake with no significant difference in daily gain compared to steam rolling and steam flaking at atmosphere pressure. In other California experiments, the same results have been found, unless more severe steaming pressure was applied. Then gains also decreased due to a severe decrease in intake (Garrett et al., 1966, 1967 and Garrett, 1968). Flatness of the flake, which is partially influenced by rolling rate, also affects efficiency (Hale et al., 1966; Theurer et al., 1967). Arizona workers have suggested increased rolling rate (volume/unit time) for steam treated wheat, in order to obtain a thicker flake. Hale (1970a) indicated that cost of the pressure cooker may be the limiting factor when considering commercial possibilities.

Three high moisture processing procedures have shown significant potential. High moisture harvesting (may contain 30% moisture or more at harvest) and reconstitutuion (harvesting at mature moisture content, approximately 10%, then storing with added water to bring moisture up to about 30%) are two of the more common methods of high moisture harvesting. The reconstituted grains are stored in an air tight or oxygen limiting structure for optimum time of 20-30 days (Florence, Riggs, and Potter, 1968; Hale, 1970a; Martin et al., 1969; White et al., 1969; Wagner and Schneider, 1970; Martin et al., 1970). Another high moisture method under current investigation is the grinding of the entire grain head (head chopping) and storage of the product in a silo until fed. An advantage to this method would be the inherent roughage factor and the high content of high moisture grain. No additional roughage would be necessary, which would aid in times of roughage scarcity and in mixing costs. Riggs and Stilwell (1964) found that moist sorghum heads, 35% moisture, properly ground and supplimented with protein, minerals and vitamin A could be satisfactorily used as the sole source of grain and roughage for fattening steers. No significant difference in gain was obtained when they compared the head chop with ground milo, but there was a difference in feed efficiency of about 12% favoring the head chop. Wagner, Schneider, and Renbarger (1970b) found that milo head chop produced significantly higher gains than dry rolled milo, but had a decreased feed efficiency because the head chop ration contained 30% roughage as compared to only 10% in the dry rolled ration. In a later study with wheat head chop, Wagner, Croka and Martin (1973) reported that wheat head chop produced lower gains and decreased efficiency, again due to a high (36%) roughage value. There were no significant differences in efficiency, however, when gain per pound of grain intake was determined and compared to either dry rolled or high moisture harvested wheat.

Recently, an increased amount of interest has been noted in comparing high moisture harvested grains. Most research indicates that the grain must be stored in the whole rather the ground form to maintain the structural integrity of the seed and obtain maximum improvement in feed efficiency (Totusek and White, 1968; Wagner and Schneider, 1970). Riggs (1965) reported that high moisture grain must be ground before feeding or no advantage would be realized over ground dry grains. If ground, he estimated an average of 10-18% increase in feed efficiency over ground dry sorghum grain. Later, Riggs and McGinty (1970) reported that high moisture harvested and reconstituted sorghum treatments required from 7 to 15% less feed to produce an equal amount of gain compared to ground dry milo. No differences in gain were observed. Totusek and White (1968) found that high moisture harvesting improved feed efficiency by 10% over dry rolled or ground sorghum grain with no difference in rate of gain. Kansas workers indicated that little difference in intake or gain was observed between dry rolled preground reconstituted, preground high moisture harvested, or steam flaked sorghum. A slight advantage existed in feed efficiency for the steam flaked over the high moisture and dry rolled treatments, with no appreciable difference between the high moisture and dry rolled grains (Albin, 1971). Buchanan-Smith et al. (1968) noted that the dry matter digestibilities of reconstituted and steam flaked sorghum grain are apparently equal, but the reconstituted grain has a slightly higher protein digestibility.

Laboratory Comparisons

During processing techniques that exert pressure, heat, shear or strain and moisture, the starch granules within the endosperm swell to such an extent that their crystalline structure is destroyed. The degree of the disruption has been termed as gelatinization. This is a rupture or hydration that may not only cause an increase in availability but also an increase in the rate of digestion (Hastings and Miller, 1961; Erwin, 1966). The degree of gelatinization in processed grains can be measured by the disappearance of birefringence of the starch granule and estimated by a beta-amylase digestion technique (Anstaett and Pfost, 1969; Sung, 1969) Sandstedt and Mattern, (1960), Sullivan, Anderson and Goldstein (1962), Leach (1965), Williamson (1967), and Hinders (1969) discussed these techniques. Many workers have noticed an increase in performance with various degrees and types of steaming, that is primarily indicated or measured by superior feed efficiencies (Hale, 1965 a,b; Roskamp, 1965, Hale et al., 1966; Erwin 1966, 1967; Trei, Hale and Theurer, 1966; Theurer, Trei and Hale, 1967; Hale, 1967; Garrett, Lofgreen and Hull, 1968).

Unprocessed sorghum grain, which is 70-75% starch, has a very low availability (Buchanan-Smith et al., 1968). A desirable degree of gelatinization of sorghum grain appears to be near 30-40% of the starch present in the particle (Williamson, 1967; Anstaett, Sung, Pfost and Deyoe, 1969; Seib, 1970; McNeill et al., 1970). The rate of digestion has been measured in vitro by the rate of gas release and by dry matter disappearance. An increase in gas production due to processing supports the assumption that steam and/or heat treatments increase rate as well as extent of digestion (Trei, Hale and Theurer, 1970; Liang et al., 1970; Anstaett and Pfost, 1969; Hinders and Eng, 1970; Hinders, 1971; Walker et al., 1970; Hinman, 1973). In studies with high moisture harvested milo, Neuhaus and Totusek (1969) found that in vitro dry matter disappearance increased as the level of moisture increased. The greatest response occurred when sorghum was harvested at 35% moisture content, stored whole and ground prior to in vitro digestion.

In the case of reconstituted grain, little gelatinization of the starch occurs, yet the utilization of the starch is similar to that of other processing methods. Protein utilization in reconstituted grain is higher than that of other processing methods (Buchanan-Smith et al., 1968; Riggs and McGinty, 1970). This suggests that gelatinization of the starch, as the only evaluation of processed grain, has limitations. It further suggests that an alteration of the grain protein, particularly with milo, may be as important in the utilization of starch as is the alteration of the starch granule (Hale, 1970b).

CHAPTER III

STEAM FLAKED WHEAT: FEEDLOT AND *IN VITRO* STUDIES

Summary

A feedlot study involving 36 heifers was conducted to evaluate two steam flaked wheat treatments with dry rolled wheat (DRW). The steam flaked wheat treatments were: 1) steamed at atmospheric pressure for 6 minutes and flaked (SFW-6) and 2) steamed at atmospheric pressure for 12 minutes and flaked (SFW-12). Each ration contained 70% wheat and 15% sorghum (DM basis). Evaluation was based on feedlot performance, carcass merit, volatile fatty acid (VFA) concentration, *in vitro* gas production, *in vitro* dry matter disappearance (IVDMD) and degree of gelatinization.

Both SFW-6 and SFW-12 produced an increased daily intake ($P < .05$), daily gain ($P < .01$) and feed efficiency ($P < .10$) over DRW. No significant difference existed for intake, gain and efficiency between the two steam flaked wheat treatments. Treatment produced no significant effect on total or individual VFA concentration, although SFW-6 and SFW-12 tended to produce a slightly lower total VFA concentration than DRW. An increased fat thickness ($P < .01$) and lower cutability ($P < .01$) were observed with both SFW-6 and SFW-12 over DRW. Steam flaking tended to increase the particle size of the grain.

The IVDMD during the 6 hour incubation period was significantly different ($P < .05$) between each of the treatments (SFW-12 > SFW-6 > DRW). At 12 hours the IVDMD of DRW was well below ($P < .01$) both steam flaked grains, with the difference between SFW-6 and SFW-12 being smaller than at 6 hours. The 24 hour IVDMD of SFW-12 was greatest, with SFW-6 greater than DRW (N.S.). The rate and extent of gas release from SFW-6 and SFW-12 was greater ($P < .01$) than DRW during each hour of the 6 hour gas production study, with no difference between the two steam flaked grains. Gelatinization was increased significantly on the SFW-6 ($P < .05$) and SFW-12 ($P < .01$) over DRW, with no significant difference between the two steam flaked treatments.

Introduction

High wheat production in the high plains feedlot area has frequently made the price of wheat competitive with feed grains in modern cattle feeding operations. However, previous research has shown consumption and gain to be decreased and feed efficiency improved when wheat is substituted for sorghum in cattle finishing rations (Garrett, Lofgreen and Hull, 1966; Brethour, 1966; Brethour and Duitsman, 1961, 1966a; Richardson, Smith, Brent and Clary, 1967; and Hale, Theurer, Marchello, Taylor and Essig, 1970).

Steam flaking is the most common method of grain processing used in the high plains area. However, little research exists on the value of steam flaking wheat. In recent sutides by Hale et al., (1970), Eng (1970) and Cornett, Sherrod and Albin (1971), wheat appeared to be improved less by steam flaking than sorghum. It was the purpose of this study to compare different degrees of steam flaking hard red winter wheat with dry rolled wheat by utilizing both feedlot and laboratory evaluation.

Experimental Procedure

Feedlot. A finishing trial involving 36 Hereford, Angus and Hereford X Angus feeder heifers, averaging 10 months of age and 226 kg, was conducted. Animals were alloted to three treatments by means of a completley randomized block design. There were two blocks within each of two barns, with one pen per treatment within each block. Thus, there were three heifers per pen providing for four pens and 12 animals per treatments. Each breed was equally represented between treatments.

The treatments compared were: 1) dry rolled wheat (DRW), 2) wheat steamed for six minutes and flaked (SFW-6) and 3) wheat steamed for 12 minutes and flaked (SFW-12). The total ration compositions are shown in table 1. Each ration contained 70% wheat and 15% dry rolled sorghum on a DM basis. The wheat for the two steam flaked wheat treatments was steamed for either 6 or 12 minutes, and then flaked by rolling the wheat through a heavy duty 46 x 61 cm roller mill with a roller spacing of .008 cm. The dry rolled wheat, as well as the dry rolled sorghum, was rolled using the same roller and roller spacing. The wheat used was of the Triumph variety, a hard red winter wheat commonly grown in Oklahoma. Each ration was prepared and fed ad libitum once daily in an amount to provide feed availability until the next feeding. The proximate analysis data are given in table 2.

The 150 day feeding period was conducted at the Ft. Reno Research Station from January 9 to June 7, 1972. Each heifer had access to an open sided shed and an outside concrete lot. Each heifer was initially

TABLE 1. RATION COMPOSITION[1]

Ingredient	Percent
Wheat	70
Sorghum	15
Cottonseed hulls	5
Ground alfalfa	5
Soybean meal	3
Urea	0.6
Salt	0.5
Dicalcium phosphate	0.4
Calcium carbonate	0.4
Aurofac-50, mg/kg	123
Vitamin A (30,000 IU/g), mg/kg	110

[1]Dry matter basis.

TABLE 2. PROXIMATE ANALYSIS

Grain	Dry Matter	Crude Protein[1,2]	Ash[1]	Ether Extract[1]	CHO[1,3]
DRW	87.97	14.40	1.82	1.39	82.39
SFW-6	83.84	14.79	1.37	1.50	82.34
SFW-12	84.27	14.53	1.69	1.62	82.16

[1]Values expressed on 100% dry matter basis.

[2]6.25 X percent nitrogen.

[3]100 - (sum of figures for crude protein, ash and ether extract).

implanted with 200 mg of testosterone propionate and 20 mg of estridiol benzozte, and then with 24 mg of diethylstilbestrol on day 71. Initial and final weights were taken full and recorded with a 4% pencil shrink.

Midway during the trial, rumen samples were taken from each animal via stomach tube. On the day prior to sampling, the daily allowance for each pen was reduced somewhat so that the feed bunks would be emptied by the animals several hours prior to feeding. This was done to insure that all animals would eat when fed on the sampling day. Feeding was such that each heifer would be sampled 3 to 5 hours post feeding. Ruminal pH values were determined immediately after sampling, mercuric chloride added to a sub-sample to stop fermentation, and the fluid frozen for VFA analysis by gas chromatography (Erwin, Marci and Emery, 1961).

Laboratory Evaluation. The processed wheat grains were further evaluated by a 6, 12 and 24 hour *in vitro* dry matter disappearance study using a modification of the first phase of the Tilley and Terry procedure (1963), as described by Schneider (1971). In addition, the hourly rate of *in vitro* gas production was measured for six hours using a gas production method adapted from Sandstedt *et al*. (1962), as revised by Hinders and Eng (1969). The degree of gelatinization of each grain was determined as mg of maltose after incubation with beta-anylase (Sung, 1969).

Statistical analyses were conducted according to analysis of variance (AOV) methods outlined by Snedecor and Cochran (1967), with significant treatment differences being tested by LSD (least significant difference). In the feedlot study, missing values, due to the loss of an animal, were estimated using the average of the two animals left within the pen; and, the number of missing values was subtracted from the degrees of freedom in the error term of the AOV.

Results and Discussion

Feedlot. Feedlot performance, carcass merit and VFA data are given in table 3. Average daily gain was very similar between the SFW-6 and SFW-12 treatments being 1.30 and 1.31 kg, respectively. There was a considerable decrease ($P < .01$) noted, however, in gain on DRW with the gain being 1.10 kg. This difference represents an increase in gain of 19% from steamed flaking. This could possibly be due in part to an increased palatability of the steam flaked grain as indicated by a 8% average increase ($P < .05$) in consumption with SFW-6 and SFW-12. Utilization was also improved by steam flaking, as indicated by a 9% increase ($P < .10$) in feed efficiency (feed/kg gain) on the two steam flaked treatments. There was very little difference, however, in feed consumption or feed efficiency data between the steam flaked treatments, with intake being 7.23 and 7.28 kg and efficiency being 5.58 and 5.57 kg on the SFW-6 and SFW-12 treatments, respectively. The improved feed utilization on the steam flaked wheat treatments might be attributed in part to the greater intakes and gains and the subsequent dilution of maintenance. Digestibility may have also been improved. No significant difference existed between treatments for total ruminal VFA concentration; however, total VFA concentrations tended to be lower on the steam flaked wheat treatments. Thompson, Bradley and Little (1965), in a study with corn, and Martin (1973), in a study with sorghum, found that steam flaked grains tended to produce decreased total VFA concentration compared to dry rolled or ground grain.

TABLE 3. FEEDLOT PERFORMANCE, CARCASS MERIT AND VFA DATA

	DRW	SFW-6	SFW-12	$S_{\bar{x}}$
No. heifers	12	12	12	
Initial live shrunk wt, kg	231	221	227	6.82
Final live shrunk wt, kg	396	418	423	7.65
Daily feed, kg[1,5]	6.70[a]	7.23[b]	7.28[b]	0.13
Daily gain, kg[5]	1.10[d]	1.30[e]	1.31[e]	0.05
Feed/kg gain, kg[1,5]	6.12[g]	5.58[h]	5.57[h]	0.17
Dressing percent	62.69	63.07	62.55	0.49
Conformation[2]	11.58	11.33	11.17	0.16
Marbling[3]	13.50	15.00	14.25	0.72
Ribeye area, sq cm	79.87	74.97	75.10	2.73
Fat thickness, cm[5]	1.78[d]	2.51[e]	2.41[e]	0.14
KHP fat, percent	2.86	2.96	2.75	0.18
Carcass grade[2]	9.00	9.92	9.50	0.32
Cutability, percent[4,5]	50.24[d]	47.68[e]	48.08[e]	0.48
Abscessed livers	0	2	2	
Ruminal pH	5.5	5.7	5.5	0.22
Volatile fatty acids				
Total VFA, umole/ml	99.38	72.78	79.57	8.20
	--------Molar percent--------			
Acetic	38.49	40.88	38.07	1.40
Propionic	39.31	34.97	36.63	1.50
Isobutyric	1.42	1.85	1.76	0.28
Butyric	13.12	12.35	13.86	1.05
Isovaleric	1.99	2.38	2.58	0.30
Valeric	3.23	4.44	4.31	0.43
Caproic	2.43	3.14	2.79	0.29

[1]Dry matter basis

[2]U.S.D.A. grade converted to the following numerical designations: 8 = avg good, 9 = high good, 10 = low choice, 11 = avg choice, 12 = high choice.

[3]Marbling scores: 11 = slight, 14 = small, 17 = modest.

[4]Percent boneless trimmed retail cuts = 52.66 - 2.098 (fat thickness) - 0.979 (KHP %) + 0.102 (ribeye area) - 0.018 (chilled carcass weight).

[5]Values with different superscripts differ significantly:
ab: ($P < .05$)
de: ($P < .01$)
gh: ($P < .10$).

A slightly lowered concentration of propionate was observed ($P > .05$) on the SFW-6 and SFW-12 treatments resulting in a higher A:P ratio. No appreciable differences were observed in either total or individual VFA concentrations between SFW-6 and SFW-12. Ruminal pH was very similar between all three treatments.

Carcass characteristics are given in table 3. Backfat thickness was lower ($P < .01$) and cutability higher ($P < .01$) for DRW cattle with no difference among the SFW-6 and SFW-12 treatments. These differences were probably due to the lower rate of gain on DRW. No other significant treatment differences in carcass traits existed.

The particle size of each grain is given in table 4. The particle size of SFW-6 and SFW-12 were similar, both of which were much larger than DRW. The increased particle size of steam flaked wheat was also found by Bris, Dyer and Howes (1966). Hale et al. (1970) reported a smaller particle size due to brittle flakes for steam flaked wheat prepared by a more severe steaming process. They suggested a thicker, less brittle flake that could withstand mixing and handling with less breakdown might possibly be produced by less steam treatment. The decreased intake noted on the DRW treatment may perhaps be due to a palatability or dustiness problem. The geometric mean particle size of the DRW was 1232 microns. Steevens (1971) and Alexander (1973) noted improved sorghum utilization with decreasing particle size in dry ground sorghum. Hale et al. (1970) suggested that particle size of dry wheat may be less important in wheat than sorghum for efficient utilization.

Laboratory Evaluation. The IVDMD data (table 5) indicate that the rate and extent of wheat digestion were significantly increased by flaking. After a 6 hour incubation period, the DRW was lower than SFW-6 ($P < .05$) and SFW-12 ($P < .01$). The DRW produced a significantly lower ($P < .01$) IVDMD than either of the steam flaked treatments in the 12 hour period. After the 24 hour incubation period, DRW had a lower IVDMD than SFW-12 with SFW-6 being intermediate (N.S.). Moreover, the in vitro digestion increased significantly as the steaming time increased. This was most evident during the six hour in vitro digestion ($P < .05$). There was no significant difference in the 12 or 24 hour incubation between the SFW-6 and SFW-12 treatments, although their ranking remained the same as during the shorter incubation period. These findings are in direct agreement with the improvement obtained in feed efficiency with steam flaking in the feedlot trial, indicating that steam flaking may increase the digestibility of wheat, such that, it can be more efficiently utilized by the animal.

The degree of gelatinization (table 5) was significantly increased by steam flaking. Gelatinization indicates the amount of damaged starch and is expressed as mg of maltose per gram of grain (Sandstedt and Mattern, 1960; Sung, 1969). Steam flaking apparently increased the susceptability of the starch granule to enzymatic attack by destroying its crystalline structure and rendering the starch more available to microbial digestion. The degree of gelatinization of SFW-6 was 25% greater than DRW ($P < .05$) with SFW-12 being 41% greater ($P < .01$) than DRW and 13% greater ($P < .05$) than SFW-6. Cornett et al. (1971) reported an increase in gelatinization of 25% for pressure flaked wheat (45 min 2.8 kg per cm^3 pressure and 93^o C) over DRW.

In vitro gas production data are given in table 6. At each of the six hourly readings the amount of gas produced from SFW-6 and SFW-12

TABLE 4. PARTICLE SIZE

Grain	Screen Size (microns)						
	4000	2000	1000	500	250	125	Pan
	% Retained						
DRW	0.0	44.67	47.67	4.83	1.00	0.33	1.50
SFW-6	26.96	41.44	21.74	4.64	0.58	0.58	4.06
SFW-12	31.62	44.59	16.49	4.59	1.08	0.55	1.08

TABLE 5. *IN VITRO* DRY MATTER DISAPPEARANCE AND DEGREE OF GELATINIZATION

	DRW	SFW-6	SFW-12	$S\bar{x}$
IVDMD, percent[3]				
6 hour	12.25[ad]	14.30[b]	16.53[ce]	0.64
12 hour	36.63[d]	45.42[e]	47.06[e]	0.95
24 hour	60.53	61.26	62.59	0.84
Degree of Gelatinization[1,2,3]	44.1[ad]	55.3[b]	62.4[e]	3.3

[1]Dry matter basis.

[2]Mg maltose/g grain.

[3]abc: Values with different superscripts differ significantly ($P < .05$).
de: Values with different superscripts differ significantly ($P < .01$).

TABLE 6. *IN VITRO* GAS PRODUCTION[1]

	DRW	SFW-6	SFW-12	$S\bar{x}$
Hour[2]				0.24
1	21.7[a]	27.5[b]	29.0[b]	
2	10.9[a]	19.3[b]	19.0[b]	
3	8.1[a]	14.1[b]	13.5[b]	
4	8.4[a]	11.5[b]	12.2[b]	
5	7.9[a]	11.1[b]	10.1[b]	
6	6.6[a]	9.2[b]	9.4[b]	
Total[2]	63.6[a]	92.7[b]	93.2[b]	0.53

[1]Ml gas release/g dry matter.

[2]Values with different superscripts differ significantly ($P < .01$).

was significantly greater ($P < .01$) than DRW. No difference existed, however, between the steam flaked wheat treatment either within hours or in total gas production. At the end of the six hour incubation period, the total gas production from SFW-6 was 46% greater ($P < .01$) and SFW-12 was 47% greater ($P < .01$) than from DRW, which indicated greater availability with steam flaking. Hale et al. (1969) reported that the increase in gas production due to steam flaking, as opposed to dry rolling, is less with wheat than sorghum, which indicated that steam flaking improves sorghum more than wheat. Martin (1973), on the other hand, reported a 46% increase in six hour total gas production with steam flaked (25 min at atmospheric pressure) over dry rolled milo. This indicates that starch availability in hard red winter wheat may be improved by steam flaking as in sorghum but, perhaps, a shorter steaming time may be required for wheat compared to sorghum.

The data reported herein suggests that steam flaking hard red winter wheat improves intake, gain, and feed utilization under feedlot conditions. The large flakes may provide a more palatable feed that has increased availability to the animal compared to DRW. The increased performance observed in the feedlot by steam flaking wheat has been substantiated by an increased rate and extent of *in vitro* gas production and dry matter disappearance. Increased gelatinization with steam flaking suggests that the starch granules in wheat were rendered significantly more available than with dry rolling. Although there was a somewhat greater degree of gelatinization and a slight increase in IVDMD on the SFW-12 vs SFW-6 treatments, there appeared to be no difference in either *in vitro* gas production or animal performance between the two steam flaked wheat treatments.

CHAPTER IV

PROCESSED SORGHUM GRAIN: FEEDLOT AND IN VITRO STUDIES

Summary

A feedlot study involving 48 heifers was conducted to evaluate four grain sorghum processing techniques. The processed sorghum treatments were: 1) dry rolled (DR), 2) steam flaked (SF), 3) high moisture harvested (HM) and 4) head chop (HC). Evaluation was based on feedlot performance, carcass merit, volatile fatty acid (VFA) concentration, in vitro gas production, in vitro dry matter disappearance (IVDMD) and degree of gelatinization.

DR and SF produced equal daily gains, both of which exceeded HC ($P < .01$). The gain on HM was intermediate (N.S.). The daily dry matter intake of HC was equal to DR, with the intake on HM being the lowest ($P < .01$) of all treatments. The intake of SF was greater ($P < .01$) than for HM, but less ($P < .01$) than on DR or HC. SF produced the greatest efficiency (feed/kg gain) followed by HM, DR and HC, each treatment being significantly different ($P < .05$).

Ruminal pH and total VFA concentration were significantly different and inversely related across all treatments (pH: HC > SF > HM > DM). Both DR and HC produced high molar percentages of acetate ($P < .05$) and lower levels of propionate ($P < .05$) than HM and SF.

The six hour IVDMD was greater ($P < .01$) with both HM and HC than either DR or SF, but after 12 hours, SF and HC were approaching equality with HM being the highest (HC: $P < .05$; SF: $P < .01$) and DR the lowest ($P < .01$). Total IVDMD after 24 hours was greatest ($P < .01$) with HM, with SF in turn being higher ($P < .01$) than DR and HC.

SF showed a greater ($P < .01$) degree of gelatinization than DR or HM, with no difference between DR and HM.

Total *in vitro* 6 hour gas production was greatest on SF ($P < .01$). Total gas production on HM was greater ($P < .01$) than on DR which tended to be higher than on HC. Hourly gas production rates followed 6 hour total gas production, except in hour 1.

Introduction

Previous research has shown that ground grain sorghum has a considerably lower feeding value than corn, although the chemical composition or nutrient content of the two grains are rather similar (Totusek *et al.*, 1963 and Richardson *et al.*, 1956). It has been shown that the nutrient availability in sorghum and the efficiency of utilization can be increased by certain processing techniques. Various processes have been examined, and some have been shown to consistantly improve various feedlot performance traits. Steam flaking has increased daily gain and feed efficiency over dry rolling (Garrett, 1968; Buchanan-Smith *et al.*, 1968; and Hale, 1967). High moisture harvesting has produced equal gains as grinding with an increase in feed efficiency (Riggs and McGinty, 1970). Head chop was suggested by Riggs and Stilwell (1964) to give an increase in feed efficiency with no difference in gain compared to dry grinding.

Although there are numerous reports of increased utilization with various types of processing, there are few studies comparing different processing techniques. Also, there has been little attempt to evaluate processing methods by in vitro laboratory techniques. The purpose of this study was to compare four major sorghum processing techniques using both feedlot and laboratory evaluation.

Experimental Procedure

Feedlot. A finishing trial involving 48 Hereford, Angus and Hereford X Angus feeder heifers, averaging 10 months of age and 229 kg, was conducted. Animals were alloted to four treatments by means of a completely randomized block design. The design was such that there were two blocks within each of two barns, four pens per block and three animals per pen. This allowed for one pen per treatment within each block; however, due to an insufficient number of pens in one barn, one pen from one barn had to be fed in the second barn. This caused one treatment (DR), selected at random, in one of the blocks to be translocated. Overall, there were four pens, three animals per pen, and 12 animals per treatment. Each breed was equally represented between treatments.

The processed sorghum treatments compared were: 1) dry rolled (DR), 2) steam flaked (SF), 3) high moisture harvested (HM) and 4) head chop (HC). The ration compositions are shown in table 7. Sorghum used in the DR and SF treatments was harvested at approximately 14% moisture and stored in a conventional grain bin. The SF was steamed for 25 minutes at atmospheric pressure preceeding rolling; the DR received no preliminary processing. Both were rolled through a 46 x 61

TABLE 7. RATION COMPOSITION[1]

	DR	SF	HM	HC
	%	%	%	%
Sorghum	84	84	84	94
Cottonseed hulls	5.0	5.0	5.0	0.0
Alfalfa meal	5.0	5.0	5.0	0.0
Soybean meal	4.2	4.2	4.2	4.0
Urea	0.6	0.6	0.6	0.6
Salt	0.3	0.3	0.3	0.3
Dicalcium phosphate	0.4	0.4	0.4	0.4
Calcium carbonate	0.4	0.4	0.4	0.4
Aurofac-50, mg/kg	123	123	123	150
Vitamin A (30,000 IU/ g), mg/kg	110	110	110	99

[1]Dry matter basis.

TABLE 8. PROXIMATE ANALYSIS

Grain	Dry Matter	Crude Protein[1,2]	Ash[1]	Ether Extract[1]	CHO[1,3]
DR	85.26	10.54	0.97	1.46	87.03
SF	80.59	10.67	0.74	1.39	87.20
HM	67.44	11.95	1.32	2.39	84.34
HC	47.53	11.56	5.58	3.32	79.54

[1]Values expressed on 100% dry matter basis.

[2]6.25 X percent nitrogen.

[3]100 - (sum of figures for crude protein, ash and ether extract).

cm heavy duty roller mill with a roller spacing of .008 cm. The HM was harvested containing approximately 30% moisture and stored in an oxygen limiting silo. Just before feeding, it was rolled using the same roller and roller spacing as mentioned above. The HC was harvested using a self propelled field chopper equipped with an adjustable cutter head. The head was raised to cut the sorghum at a height at which all of the heads could be harvested with a minimum of stubble and leaf material included. The harvested head chop material was then processed through a hammermill containing a recutter as it was blown into an oxygen limiting silo. The particle size was reduced by the recutter the extent that most of the sorghum kernels were broken. It was then fed using no further processing method. Each ration was fed ad libitum once daily in an amount to provide feed availability until the next feeding. The proximate analysis data are given in table 8.

The 150 day feeding period was conducted at the Ft. Reno Research Station from January 9 to June 7, 1972. Each heifer had access to an open sided shed and an outside concrete lot. Each heifer was initially implanted with 200 mg of testosterone propionate and 20 mg of estridiol benzoate and then, with 24 mg of diethylstilbestrol on day 71. Initial and final weights were taken full and recorded with a 4% pencil shrink.

Midway during the trial, rumen samples were taken from each animal via stomach tube. On the day prior to sampling, the daily allowance for each pen was such that the feed bunks would be emptied by the animals several hours prior to feeding. This was done to insure that all animals would eat when fed on the day of sampling. Feeding was such that each heifer would be sampled 3 to 5 hours post feeding. Ruminal pH values were determined immediately after sampling, mercuric chloride added to a sub-sample to stop fermentation, and the fluid frozen for VFA analysis by gas chromatography (Erwin, Marci and Emery, 1961).

Laboratory Evaluation. The treatments were further evaluated by a 6, 12 and 24 hour *in vitro* dry matter disappearance (IVDMD) study using a modification of the first phase of the Tilley and Terry procedure (1963) as described by Schneider (1971). In addition, the hourly rate of *in vitro* gas production was measured for six hours using a method adapted from Sandstedt *et al.* (1962), as revised by Hinders and Eng (1969). The degree of gelatinization of each grain was determined as mg of maltose after incubation with beta-amylase (Sung, 1969).

Statistical analyses were conducted according to analysis of variance (AOV) methods methods outlined by Snedecor and Cochran (1967), with significant treatment differences being tested by LSD (least significant difference). In the feedlot study, missing values, due to the loss of an animal, were estimated using the average of the two animals left within the pen; and, the number of missing values was subtracted from the degrees of freedom in the error term of the AOV. Data from each animal, within the one pen that was displaced by barn, were adjusted to the appropriate block within barn by using the average difference between barns within each trait. The data were then analyzed as within the block and barn to which the pen was initially assigned.

Results and Discussion

Feedlot. The feedlot performance data are given in table 9. Treatment had a significant effect on daily gain, feed intake and feed efficiency (kg feed/kg gain). Cattle on the DR and SF rations had the

TABLE 9. FEEDLOT PERFORMANCE, CARCASS MERIT AND VFA DATA

	DR	SF	HM	HC	$S_{\bar{x}}$
No. heifers	12	12	12	12	
Initial live shrunk wt, kg	228	227	228	232	6.11
Final live shrunk wt, kg	402	401	387	373	8.64
Daily feed, kg[1,5]	7.82^{d}	6.62^{e}	6.45^{f}	7.82^{d}	0.05
Daily gain, kg[5]	1.28^{d}	1.28^{d}	1.15^{de}	1.03^{e}	0.04
Feed/kg gain, kg[1,5]	6.14^{a}	5.19^{b}	5.62^{c}	7.63^{d}	0.14
Dressing percent[5]	63.48^{d}	63.86^{d}	63.55^{d}	61.15^{e}	0.45
Conformation[2,5]	11.08^{a}	11.33^{ab}	11.83^{b}	10.92^{a}	0.22
Marbling[3]	13.67	12.75	11.92	11.08	0.68
Ribeye area, sq cm	76.19	75.35	72.71	72.45	2.06
Fat thickness, cm	2.03	2.18	2.44	1.93	0.14
KHP fat, percent[5]	2.90^{d}	2.29^{e}	2.53^{de}	2.13^{e}	0.16
Carcass grade[2]	9.00	8.92	9.08	8.75	0.24
Cutability, percent[4]	48.94	49.16	48.23	49.90	0.50
Abscessed livers	0	4	3	0	
Ruminal pH[5]	5.7^{d}	6.2^{e}	5.9^{de}	6.7^{f}	0.12
Volatile fatty acids					
Total VFA, umole/ml[5]	96.41^{a}	70.85^{b}	84.71^{ab}	64.06^{b}	5.51
	----------Molar percent----------				
Acetic[5]	45.48^{a}	36.66^{b}	39.29^{b}	48.42^{a}	1.92
Propionic[5]	35.36^{a}	41.27^{a}	35.74^{a}	26.49^{b}	2.36
Isobutyric[5]	1.52^{d}	1.60^{d}	1.38^{d}	2.21^{e}	0.11
Butyric[5]	9.38^{a}	10.77^{ab}	13.87^{b}	11.72^{ab}	1.20
Isovaleric[5]	2.61^{ab}	2.39^{a}	2.11^{a}	3.10^{b}	0.23
Valeric[5]	3.12^{a}	4.60^{b}	4.93^{b}	4.64^{b}	0.40
Caproic[5]	2.49^{a}	2.70^{a}	2.67^{a}	3.42^{b}	0.24

[1]Dry matter basis.

[2]U.S.D.A. grade converted to the following numerical designations: 8 = avg good, 9 = high good, 10 = low choice, 11 = avg choice, 12 = high choice.

[3]Marbling scores: 11 = slight, 14 = small, 17 = modest.

[4]Percent boneless trimmed retail cuts = 52.66 - 2.098 (fat thickness) - 0.979 (KHP %) + 0.102 (ribeye area) - 0.018 (chilled carcass wt).

[5]abc: Values with different superscripts differ significantly ($P < .05$).
def: Values with different superscripts differ significantly ($P < .01$).

highest average daily gain, (1.28 kg) and, the cattle on the HC the lowest (1.03 kg), with HM being intermediate (1.15 kg). Gains on the HC and HM were significantly different at the .01 and .05 levels, respectively, compared to DR and SF treatments. Riggs and McGinty (1970) also found slightly lower gain with HM compared to ground sorghum. Average daily consumption on DR and HC was increased 15% ($P < .01$) over SF, and 18% ($P < .01$) over HM. in addition, there was a 3% lower ($P < .01$) consumption with HM compared to SF. The feed efficiency of DR, SF, HM and HC was 6.14, 5.19, 5.62 and 7.63 kg, respectively. Each treatment was significantly different ($P < .05$) from each of the other three treatments. In previous work with HM, Riggs and McGinty (1970) found that feed efficiency was improved 22% over dry ground milo. Moreover, Totusek and White (1968) indicated a 10% advantage for HM over ground for dry rolled sorghum. In this study feed efficiency was increased 15% with SF and 8% with HM, but decreased 24% with HC when each was compared to DR.

At first glance, the HC seems to be consistantly inferior to the other three rations. However, if consideration is given to its high roughage content the respective performance traits are quite acceptable. Riggs et al. (1964), producing sorghum HC in a manner very similar to that in this study, obtained a HC product characterized as containing 70% grain and 30% roughage. In work with HC and DR sorghum, Wagner, Schneider and Renbarger (1970b) also found that more total dry matter was required per unit gain compared to a 90% concentrate, DR sorghum ration.

Ruminal pH and total VFA concentration (table 9), were significantly different and were inversely related across all treatments.

In studies with varying levels and forms of roughage and grain, Balch and Rowland (1957), Thompson, Bradley and Little (1965) and White and Reynolds (1969) each found this inverse relationship to exist. The ruminal pH on HC was higher ($P < .01$) compared to all other treatments, with the pH on SF also being higher ($P < .01$) than on DR. The ruminal pH on HM was between DR and SF (N.S.). The total VFA concentration on DR was higher ($P < .05$) than on SF and HC, with SF slightly higher than HC (N.S.). The total VFA concentration on HM was between DR and SF.

Numerous differences were observed in individual VFA concentrations. The molar percent of acetic acid on DR and HC were higher ($P < .05$) than on SF and HM, with a significant decline in propionate ($P < .05$) being observed only with HC. Thompson *et al.* (1965) also found a rise in acetate and a decline in propionate with rations composed of higher roughage levels, which, therefore, was accompanied by a wider acetate to propionate (A:P) ratio. The increase in A:P ratio was also indicated by this data. There was also an increase observed in isobutyric ($P < .01$), isovaleric ($P < .05$) and caproic ($P < .05$) acids with HC as compared to DR, SF and HM. A decrease ($P < .05$) in butyric and valeric acids was noted with DR as compared to HM.

Some differences in carcass characteristics were observed (table 9). There was no difference between dressing percent of the DR, SF, and HM, but there was a significant decrease ($P < .01$) with HC. A significant decrease was observed in conformation with both DR and HC ($P < .05$) compared to HM. A decrease in percent KHP fat was observed with SF and HC ($P < .01$) compared to HM. Moreover, marbling, fat thickness, rib eye area and carcass grade tended to be lower and cutability higher on the HC treatment. The observed carcass differences may have been due to the difference in rate of gain between treatments and suggest only that rations producing low daily gains require a longer feeding period.

The particle size of each grain is given in table 10. The particle size of DR was slightly greater than HM, but was much less than SF. The geometric mean particle size of DR was 802 microns. An increased particle size of SF over DR has been noted by other researchers (Totusek, *et al.*, 1967; Newson, 1968; and White, 1969).

Laboratory Evaluation. During the 6, 12 and 24 hour incubation IVDMD trial (table 11) the various treatments reacted differently within each time period. At the 6 hour interval, HM and HC were 31% more digested than either DR or SF ($P < .01$). No statistical difference existed between DR and SF or between HM and HC. After the 12 hour digestion period, SF and HC were approaching equality, with HM significantly greater than both (SF: $P < .01$; HC: $P < .05$). At this point, the digestion of DR was much below ($P < .01$) the other three treatments, However, after 24 hours the total digestion of HM was 13% greater than DR ($P < .01$). SF was digested 20% greater than HC ($P < .01$) and 21% greater than DR ($P < .01$). There was no significant difference between DR and HC in total IVDMD at 24 hours.

These findings suggest that both HM and HC may contain more rapidly fermentable substrates, such as sugars, than DR and SF; however, HM and SF may be more completely digested and utilized than either DR or HC. The greater total 24 hour IVDMD for the SF and HM treatments agrees with the improvements noted in feed efficiency on these same treatments in the feedlot trial, suggesting improved starch

TABLE 10. PARTICLE SIZE

Grain	Screen Size (microns)						
	4000	2000	1000	500	250	125	Pan
	% Retained						
DR	0.0	3.99	79.07	9.42	2.24	1.29	3.99
SF	7.59	58.48	21.27	6.33	2.03	1.01	3.29
HM	0.0	32.45	37.76	9.44	5.90	4.42	10.03

TABLE 11. *IN VITRO* DRY MATTER DISAPPEARANCE AND DEGREE OF GELATINIZATION

	DR	SF	HM	HC	$S_{\bar{x}}$
IVDMD, percent[3]					
6 hour	10.91^{d}	10.97^{d}	14.32^{e}	14.45^{e}	0.59
12 hour	21.73^{d}	35.28^{f}	39.48^{ae}	36.64^{bef}	0.83
24 hour	39.56^{d}	47.99^{e}	54.43^{f}	40.01^{d}	1.39
Degree of Gelatinization	16.4^{d}	54.5^{e}	18.3^{d}	----	1.3

[1]Dry matter basis.

[2]Mg maltose/g grain.

[3]ab: Values with different superscripts differ significantly ($P < .05$).
def: Values with different superscripts differ significantly ($P < .01$).

TABLE 12. *IN VITRO* GAS PRODUCTION[1]

	DR	SF	HM	HC	$S_{\bar{x}}$
Hours[2]					0.39
1	17.4^{a}	19.9^{b}	16.0^{c}	28.7^{d}	
2	10.1^{a}	17.6^{b}	12.0^{c}	9.2^{d}	
3	8.7^{a}	15.0^{b}	11.0^{c}	4.8^{d}	
4	8.8^{a}	14.6^{b}	12.9^{c}	5.8^{d}	
5	8.2^{a}	12.8^{b}	13.5^{b}	4.0^{c}	
6	7.5^{a}	10.0^{b}	10.0^{b}	4.0^{c}	
Total[2]	60.7^{a}	89.9^{b}	75.4^{c}	56.5^{a}	1.60

[1]Ml gas release/g dry matter.

[2]Values with different superscripts differ significantly ($P < .01$).

utilization from steam flaking and high moisture harvesting sorghum.

The significant difference ($P < .01$) in gelatinization between the DR and SF treatments (16.4 vs 54.5) and the HM and SF treatments (18.3 vs 54.5) are in direct agreement with the data obtained in feed efficiency and IVDMD. The higher degree of gelatinization in the SF grain suggests that the starch component in the grain is more available for enzymatic breakdown. Gelatinization has frequently been used to refer to alterations in the starch granules caused by heat, moisture and/or pressure. In this regard, the somewhat similar gelatinization values observed between the DR and HM (16.4 and 18.3) grains suggests that starch availability is being enhanced by some other means in HM sorghum grain. Possibly, the carbohydrates in HM harvested sorghum are in a more available form with smaller molecules and more simple sugars being present. Perhaps the proteinacious matrix surrounding the starch granules in HM sorghum is not completely formed and is less resistant to enzymatic attack. In recent studies with reconstituted sorghum grain, the improved feed utilization has also been suggested to be related to an increased digestibility of the protein matrix (Hale _et al_., 1966; Buchanan-Smith _et al_., 1968; Riggs and McGinty, 1970; Hale, 1970b). Riggs and McGinty (1970) suggested that in dry grain the starch molecules are encapsulated by a protein matrix and are, therefore, protected from amylolytic enzymes produced by both the microflora and the animal.

The difference in total 6 hour in vitro gas production (table 12) between DR and HC was not significant ($P < .05$) although HC tended to be lower. However, the difference between all other treatment combinations was highly significant ($P < .01$). Gas release from SF was

19% greater than HM, 46% greater than DR and 59% greater than HC. Gas release from HM was 23% greater than DR and 33% greater than HC.

The ranking for total 6 hour gas production on each treatment was in direct agreement with the ranking for feed efficiency in the feedlot; however, the magnitude of increase in gas production was much greater than the increase observed in feed efficiency. The rates of gas production for each hour during the 6 hour period were also significant. The rank in rate of hourly gas production was in agreement with both the total gas production and feed efficiency data with the exception of hour 1. In hour 1 HC produced the largest quantity of gas of all treatments ($P < .01$), and DR produced more ($P < .01$) than HM. The rate of gas production for HC in hour 1 was in agreement with the findings on IVDMD in that a rapid initial digestion was observed with HC, with a much reduced rate of digestion thereafter.

The data reported herein suggests that sorghum HC produces a lower gain and decreased feed efficiency compared to DR, SF or HM sorghum fed in high concentrate finishing rations. This difference can be accounted for by its higher roughage, lower concentrate content and suggests that sorghum HC might be more appropriately used in grower rather than finishing programs due to its lower energy content. Moreover, both SF and HM sorghum significatnly increased the efficiency of utilization in finishing cattle compared to DR sorghum and this was substantiated by significant increases in IVDMD and *in vitro* gas production in the laboratory.

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APPENDIXES

TABLE 13. AOV FOR FEEDLOT TRIALS: ADG, CARCASS AND pH DATA

Source	df	MS									
		ADG	DP	Conf	Marb	REA	BF	KHP	Grade	Cutab	pH
(Wheat)											
Total	33										
Barn (B)	1	0.0005	3.0800	0.6944	66.6944	28.3298	0.3347	0.0400	3.3611	3.5004	1.7778
Blk/B[1]	2	0.0175	6.7567	0.8056	49.4722	2.4383	0.8939	0.1122	6.1389	6.0787	0.4428
Trt[2]	2	0.1756[a]	0.8781	0.5278	6.7500	94.0104	2.3090[b]	0.1303	2.5278	22.8642[b]	0.2775
B X Trt	2	0.0002	8.1001	0.5278	0.3611	32.3172	0.1346	0.1608	0.1944	0.8794	0.0169
Blk/B X Trt	4	0.0365	3.8186	0.3056	16.7222	161.3343	0.3210	0.3289	3.6389	4.6844	0.2144
Within pen[3]	22	0.0327	2.9331	0.3030	6.2727	89.9501	0.2929	0.3921	1.2424	2.7305	0.5755
(Sorghum)											
Total	46										
Barn (B)	1	0.0427	7.5843	1.3333	0.5208	27.1938	0.2761	1.3669	0.1875	0.0006	0.5633
Blk/B[1]	2	0.0230	2.0042	0.3750	4.6875	74.4057	0.4697	1.8002	1.5208	11.4794	0.5254
Trt[2]	3	0.1657[b]	18.7323[b]	1.9167[a]	14.7431	41.6112	0.5720	1.3535[b]	0.2431	5.6640	2.1903[b]
B X Trt	3	0.0111	2.6613	3.1667	6.7986	32.6383	0.0228	0.1341	0.6875	0.0241	0.5928
Blk/B X Trt	6	0.0195	8.3190	0.7639	3.9653	20.6448	0.1981	0.2841	1.4653	2.0718	0.7138
Within pen[3]	31	0.0225	2.4463	0.5807	5.5054	50.8060	0.2490	0.2890	0.7097	2.9505	0.1798

[1]Block within barn.

[2]Treatment MS with superscript is significant:
a: ($P < .05$).
b: ($P < .01$).

[3]Error term used in testing for significant treatment effect.

TABLE 14. AOV FOR VFA DATA

Source	df	MS							
		A	P	IB	B	IV	V	C	Total
(Wheat)									
Total	69								
Barn (B)	1	344.9479	16.0904	4.8989	26.9126	1.9250	10.8884	6.1168	2636.3239
Blk/B[1]	2	23.8609	8.6442	0.0716	29.6849	0.1683	1.0805	0.6567	965.1810
Trt[2]	2	55.1156	115.1122	1.2158	13.7653	2.1028	10.5762	2.9753	4584.9501
B X Trt	2	20.5643	22.0890	0.3319	7.7610	0.1029	0.7282	1.9173	582.3110
Blk/B X Trt	4	139.5643	41.0216	0.7088	88.0771	0.9506	1.0524	0.7194	365.5855
Within pen[3]	23	46.7146	53.8118	1.9298	26.5912	2.1274	4.4558	1.9987	1612.9922
Within animal	35	3.3470	1.3795	0.0294	0.2160	1.3019	0.1427	0.0702	31.4830
(Sorghum)									
Total	93								
Barn	1	56.4487	393.7082	0.9150	71.1866	2.7655	0.2027	2.7255	532.1825
Blk/B[1]	2	102.4556	130.9465	1.9632	135.1902	3.8838	6.6985	5.3760	3927.2767
Trt[2]	3	706.4629[b]	895.9151[b]	3.2792[b]	85.4207[a]	4.1722[b]	15.9593[b]	3.9867[b]	5002.0405[b]
B X Trt	3	40.2680	66.5449	0.2500	14.3571	0.6795	0.0400	0.8809	2380.0003
Blk/B X Trt	6	56.3711	55.5958	0.6097	22.7784	1.9381	1.0183	1.0138	401.8034
Within pen[3]	31	44.3941	66.5526	0.1491	17.2034	0.6157	1.8883	0.7065	729.4354
Within animal	47	0.9893	0.7635	0.0197	0.2028	0.2636	0.1431	0.0191	12.5940

[1]Block within barn.

[2]Treatment MS with superscript is significant:
a: ($P < .05$).
b: ($P < .01$).

[3]Error term used in testing for significant treatment effect.

TABLE 15. AOV FOR FEEDLOT TRIALS: ADC AND F/G DATA

Source	df		MS			
			ADC		F/G	
(Wheat)						
Total	11					
Barn (B)	1		0.7632		0.0246	
Trt[1]	2		0.4183[b]		0.4025[a]	
B X Trt[2]	2	8	0.0195	0.0534	0.0053	0.1176
Residual[2]	6		0.0646		0.1550	
(Sorghum)						
Total	15					
Barn (B)	1		0.0723		0.2742	
Trt[1]	3		2.2453[c]		4.5287[c]	
B X Trt	3		0.0274		0.1593	
Residual[2]	8		0.0117		0.2468	

[1]Treatment MS with superscript is significant:
a: ($P < .10$).
b: ($P < .05$).
c: ($P < .01$).

[2]Error term used in testing for significant treatment effect (pooled in wheat trial).

TABLE 16. AOV FOR IVDMD DATA

Source	df	MS		
		6	12	24
(Wheat)				
Total	17			
Trt[1]	2	27.5578[a]	188.7715[a]	6.5269
Within trt[2]	15	2.4217	5.4043	4.2401
(Sorghum)				
Total	23			
Trt[1]	3	23.7901[a]	374.5099[a]	302.7701[a]
Within trt[2]	20	2.0984	4.1536	11.6405

[1]Treatment MS with superscript is significant ($P < .01$).

[2]Error term used in testing for significant treatment effect.

TABLE 17. AOV FOR GELATINIZATION DATA

Source	df	MS
(Wheat)		
Total	11	
Replicate	1	1.6651
Trt[1]	2	3.4148[a]
Residual[2]	8	0.4320
(Sorghum)		
Total	9	
Replicate	1	0.0867
Trt[1]	2	18.4511[b]
Residual[2]	6	0.0717

[1]Treatment MS with superscript is significant:
a: ($P < .05$).
b: ($P < .01$).

[2]Error term used in testing for significant treatment effect.

TABLE 18. AOV FOR <u>IN VITRO</u> GAS PRODUCTION DATA

Source	df	MS
(Wheat)		
Total	47	
Main plot[1]	7	
Trt	2	126.7619[b]
Within trt	5	0.7106
Sub plot[1]	40	
Hour (H)	5	344.5765[b]
H X Trt	10	6.4432[b]
Residual	25	0.9239
(Sorghum)		
Total	71	
Main plot[1]	11	
Trt	3	99.8368[a]
Within trt	8	7.6348
Sub plot[1]	60	
Hour (H)	5	75.0688[b]
H X Trt	15	7.6348[a]
Residual	40	2.7929

[1]MS with superscript is significant:
a: ($P < .05$).
b: ($P < .01$).

VITA

Thomas Stephen Martin

Candidate for the Degree of

Master of Science

Thesis: FEEDLOT AND IN VITRO STUDIES WITH PROCESSED SORGHUM AND WHEAT

Major Field: Animal Sciences and Industry

Biographical:

Personal Data: Born in Muleshoe, Texas, April 17, 1950, the son of Mr. and Mrs. W. J. Martin and married Linda Hamilton, May 20, 1972.

Education: Graduated from Dimmitt High School, Dimmitt, Texas, in May, 1968. Received the Bachelor of Science degree from Texas Tech University in Lubbock, Texas, in August, 1972, with a major in Animal Science (option: Animal Production).

Experience: Reared on a livestock and farming operation in the West Texas community of Flagg. Livestock judging team member at Texas Tech University, 1969-70. Graduate assistant at Oklahoma State University, 1972-73.