METHODS OF PROCESSING GRAIN

FOR LACTATING DAIRY COWS

By

BARRY JEROME STEEVENS

Bachelor of Science
Wisconsin State University
River Falls, Wisconsin
1966

Master of Science
Oklahoma State University
Stillwater, Oklahoma
1968

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
DOCTOR OF PHILOSOPHY
July, 1971

METHODS OF PROCESSING GRAIN

FOR LACTATING DAIRY COWS

Thesis Approved:

L. J. Bush
Thesis Adviser

Eldon Nelson

Robert D Morrison

W. S. Newcomer

D G Wagner

D Durham
Dean of the Graduate College

ACKNOWLEDGEMENTS

The author wishes to express sincere appreciation to Dr. Linville J. Bush for his competent advice, guidance and invaluable assistance during the course of this study and the preparation of this thesis.

Appreciation is extended to Glendon Adams and Lyle Sallee for the care of the experimental animals; to Dr. E. I. Williams for his sincere interest and veterinary service; and to John Cunningham, Rondal Alexander and Mario Gonzalez for their assistance with the data collection and laboratory analysis.

The author wishes to thank Dr. R. D. Morrison, Dr. D. G. Wagner, Dr. E. C. Nelson and Dr. W. S. Newcomer for their valuable guidance, counciling and assistance in conducting this study and preparation of this manuscript.

The author is grateful to Mrs. Janet Sallee for her work in typing and editing of this study. Special apprecia*ion is expressed to the author's wife, Kay and children, Lori and Jeffery for their patience and sacrifice during the course of graduate study and during the preparation of this thesis. Much appreciation is expressed to the author's parents Mr. and Mrs. Jerome Steevens and to Mr. and Mrs. Herbert Nuernberger for their encouragement during this study.

Thanks are expressed to the Department of Animal Sciences and Industry for financial assistance during the author's graduate program.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

Sorghum grain is a common ingredient of concentrate rations fed to dairy cattle in the southwestern United States. One reason for the widespread use of sorghum grain is the plant's ability to grow well under hot and dry environmental conditions. The importance of processing the grain to the extent of breaking the kernels by grinding or rolling has been well documented; however, the optimal particle size in terms of animal production has not been clearly defined. The value of reconstituting, steam flaking, pelleting, exploding, or micronizing sorghum grain in dairy rations has not been established. The results of work on processing grain for beef cattle rations cannot be applied directly to lactating dairy cattle because the grain comprises a different proportion of the total ration for dairy cows, and the effects on both composition and yield of milk must be considered. Also, dairy cows consume more feed per unit of body weight than fattening beef cattle. It is well established that very high grain levels in rations such as those fed to beef cattle lower the rumen acetate percentage and raise the propionate percentage which is associated with a sharp decrease in the milk fat percentage. The extent to which processing grain in different ways may improve its utilization by dairy cows without detrimental effects on milk composition needs to be determined.

This study was undertaken to determine an optimal particle size of sorghum grain for use in rations fed to lactating dairy cows. The response criteria were milk yield and composition, body weight, rumen volatile fatty acids (VFA) percentages and concentrations, and apparent digestibility of ration components.

CHAPTER II

REVIEW OF LITERATURE

Methods of Grain Preparation

Grinding

The importance of grinding grain for dairy cows was clearly demonstrated many years ago. Wilbur (1933) observed that dairy cows utilized ground corn and oats more efficiently than they did whole corn and oats. He reported that 20 to 35% of the unground oats and corn that were fed was recovered in the feces as undigested grain. Also, the fecal starch content was highest for the cows fed the "whole grain" ration as compared to that of the "medium ground grain" ration. Since sorghum grain is small and hard it is apparently more apt than some other grains to pass through the cow undigested. Atkeson and Beck (1942) suggested that the protective hull of the seed must at least be cracked in order to permit the digestive juices to act most effectively upon the nutrients in the grain. Grinding of sorghum grain was found to be especially important because relatively large losses (40 to 60%) occurred in the feces when it was fed unground; whereas, the loss was reduced to 4.8 and 1.5%, respectively, by coarse and fine grinding (Fitch and Wolberg, 1934; Atkeson and Beck, 1942).

There is evidence suggesting that the effect of grinding to different degrees of fineness is related to the type of grain fed. Wilbur (1933) reported that cows fed medium ground corn and oats produced more milk and fat per 100 pounds of grain fed than did cows fed pulverized or coarsely ground corn and oats. Wilbur (1933) and Olson (1942) observed medium ground corn and oats to be equal or superior to finely ground corn and oats in terms of milk production response. Olson (1942) also found that coarsely ground corn and oats was equal to finely ground grain in terms of digestibility, and the coarsely ground grain was more palatable than the finely ground grain. Darnell and Copeland (1936) observed that lactating cows consumed more concentrates and produced more milk when the concentrate mixture contained 60% ground sorghum grain than when whole sorghum grain was used.

There is considerable evidence that in beef cattle rations fine grinding (1/8 inch hammer mill screen) improves the digestibility of sorghum grain over dry rolling or coarse grinding (Smith, Parrish and Pickett, 1949; Smith and Parrish, 1952; Newsom et al., 1968; Totusek, 1969; White et al., 1969b), although this has not been found in all trials reported (Mehen et al., 1966; Buchanan-Smith, Totusek and Tillman, 1968).

White et al. (1969b) found improved feed efficiency when very finely ground (1/16 inch screen) sorghum grain was compared to finely ground grain for fattening beef steers. They did not observe a marked decrease in feed intake and gain because of the floury texture of the very finely ground sorghum grain.

Pelleting

The effects of pelleting the concentrate portion of the ration for dairy cows appear to be related to the proportion of concentrates in the total ration and the composition of the grain mixture. Adams and Ward

(1956) reported that pelleting of the concentrate ration had no effect on milk yield, but decreased the milk fat percentage. Separate palatability trials indicated that the pelleted and mash concentrates were equally acceptable to most cows. Bishop et al. (1963) observed an increase in milk production and only a slight decrease in fat test as a result of pelleting a high-fiber concentrate mixture for dairy cows. There were very small differences in feed intake in favor of the meal type concentrate, but the efficiency of utilization of total digestible nutrients (TDN) for the production of fat corrected milk was slightly higher for pellets. Fountaine and Bartley (1962) obtained higher milk production and no change in fat test from cows fed ground and pelleted sorghum grain as compared to steam rolled or cold cracked grain.

Brown et al. (1970) studied the effects of steam processed versus pelleted milo and barley as well as different proportions of milo and barley where the grain constituted 33% of the total ration. Neither processing technique, i.e., steam flaking or pelleting, nor the proportions of the two grains had any effect on milk yield, percent fat and non-fat solids, or digestibility of various feed components. Milk fat percentages for the different ration treatments ranged from 2.86 to 3.08, which is slightly low for the Holstein breed. Molar percentages of rumen acetate and propionate were approximately 38 and 29%, respectively, and very similar to values reported by Balch et al. (1955a) for cows fed a low milk fat producing ration.

Some workers have indicated that finely ground and pelleted sorghum grain increases the average daily gain and feed efficiency of beef cattle as compared to beef cattle fed coarse ground and steam rolled sorghum grain (Pope, Urban and Waller, 1959; Totusek, 1969). However, Totusek

(1969) noted that pelleting has rather consistently resulted in a 1% decrease in dressing percentage and a slight lowering of carcass grade which tends to eliminate much of the advantage in feed efficiency. Ralston et al. (1963) observed that finely ground and pelleted sorghum grain significantly reduced average daily gain as compared to grain coarsely ground or steam rolled. McCroskey et al. (1960) reported an improved performance of fattening steers due to pelleting a high roughage ration, but no improvement from pelleting a high concentrate ration containing ground milo as the main ingredient. In many of these studies comparing different processing methods, particle size of the final product has been confounded with other processing characteristics so that a definite conclusion is not possible.

Conventional Steam Rolling

Conventional steam rolling has been a commonly used method of processing sorghum grain, but the conditions for the process are variable and not well defined in terms of the amount of heat and pressure to which the grain is subjected. On the basis of four trials, Totusek (1969) concluded that steam rolling of sorghum grain has no advantage over dry rolling in terms of either rate of gain or feed efficiency. Garrett (1965) observed no consistent advantage in weight gains of beef cattle fed steam rolled versus ground (1 cm screen) sorghum grain and barley. Moreover, steam rolling did not significantly increase acceptability of sorghum grain as compared to ground grain when *ad libitum* consumption was permitted. Alego, Brannum and Hibbits (1968) found that steam rolled sorghum grain was similar to steam rolled barley and exploded sorghum grain in terms of average daily gain, feed consumption and feed conversion by steers. Bush et al. (1964) found no advantage in terms of milk production response of dairy cows for steam rolled and finely ground (3/64 inch screen) sorghum grain as compared to grain finely ground only, or steam rolled, finely ground and dry heated. On the other hand, Fountaine and Bartley (1962) found that steam rolled grain was superior to dry rolled grain in terms of milk yield, but not equal to ground and pelleted grain.

Steam Flaking

Studies concerned with steam flaking grain for dairy cows deal more with changes in milk composition than with the matter of milk production efficiency. Balch et al. (1954), Balch et al. (1955b) and Shaw (1958, 1959) observed a greater decrease in the fat content of milk from dairy cows fed high concentrate rations in which the grain had been steam heated (flaked) than in the milk from those fed the same rations with unheated grains. This difference was presumed to be due to the heat treatment imposed on the grain, although the effects of heating were not determined independently of the effects of feeding different forms of the grain (rolled vs. ground). Nevertheless, Balch et al. (1955b) suggested that the greater effectiveness of flaked maize, as compared to uncooked maize meal, in depressing the fat content of milk was due to rupture and partial dextrinization of the starch granules by passage between heated rollers in the flaking process. This change in milk fat content, noted when cows were fed low roughage-high concentrate rations, was found by Balch et al. (1955a) to be associated with a lowered proportion of acetate and an increased proportion of propionate in the rumen; however, Balch et al. (1954) and Shaw et al. (1959) showed that these changes do not occur when certain commonly used concentrate mixtures are fed. The degree of "fibrousness" and digestible starch content were cited by Balch et al. (1954) as important factors in determining whether a given diet would cause a decrease in milk fat content. As mentioned earlier, Brown et al. (1970) found essentially no difference between pelleted and steam processed concentrates containing different proportions of milo and barley.

Improvement in the weight gain of beef cattle fed steam flaked sorghum grain has been reported by several workers (Hale et al., 1966; Garrett, Lofgreen and Hull, 1968; Hale, 1968; Totusek, 1969; Wagner, Schneider and Renbarger, 1970). Phillipson (1952) reported that flaking of corn resulted in a reduction of the ratio of acetate to propionate production in the rumen and an improvement in the efficiency of feed utilization by lambs.

Significant increases in dry matter digestibility due to steam flaking of sorghum grain have been noted (Husted et al., 1968). Buchanan-Smith et al. (1968) reported higher digestibilities of dry matter, organic matter, and nonprotein organic matter of sorghum grain steam processed and rolled than for grain fine or coarsely ground. McNeill, Potter and Riggs (1969) reported that ruminal digestion of starch was greater in steers fed reconstituted and steam-flaked grain than in steers fed ground or micronized grain.

The work on different conditions for steam processing of sorghum grain, as reviewed by Hale (1968), has led to the conclusion that there is an optimal range of pressure and time of processing to obtain the greatest advantage in terms of animal performance. Hale et al. (1966) observed that by subjecting the grain to steam ($99^{o}C$) at atmospheric pressure for about 25 minutes and then rolling the grain with no tolerance on the rollers, a large flat flake was produced having approximately half the weight per volume of the original material. Garrett et al. (1968) observed that when sorghum grain was steam processed under pressure (50 to 80 p.s.i.) for 1 to 1.5 minutes, there was a decreased intake of the ration as compared to rations containing sorghum grain processed at lower pressures. They found an advantage in feed efficiency for either rolled or ground steam pressure processed sorghum grain over sorghum grain processed at atmospheric pressure, thus indicating that steam pressure treatments were influencing the feeding value of the sorghum grain in some way other than by permitting a superior rolled product to be obtained. Wagner et al. (1970) examined the influence of steaming time on the nutritive value of steam flaked sorghum grain. The grain was steamed for periods of 15, 25, 35 and 45 minutes at atmospheric pressure and then rolled through a cold roller mill with a spacing of 0.003 inch. All steam flaking treatments resulted in greater feed efficiency than dry rolled sorghum grain, but there was no consistent pattern in improvement of the grain with respect to the time of steaming. Holmes, Drennan and Garrett (1971) examined the digestibility of sorghum grain steamed for 8 minutes at atmospheric pressure before rolling as compared to grain steamed at 3.5 kg/cm^2 pressure for 1.5 minutes before rolling. The overall starch disappearance from the gastrointestinal tract averaged 97.3 and 97.6% for the steamed grain and pressure-steamed grain, respectively. Pressure steaming the grain resulted in more rapid and more nearly complete fermentation in the rumen.

In vitro studies by Osman et al. (1970) indicated that the extent of starch digestion increased as processing pressure increased from 1.4

kg/cm^2 to 5.6 kg/cm^2 and also increased with the degree of flaking. The degree of flaking (flake flatness) was cited as the principal factor influencing availability of barley and sorghum grain to *in vitro* enzymatic attack. Trei, Hale and Theurer (1970) found that *in vitro* gas production increased proportionately as cooking pressures were raised from 1.4 to 5.6 kg/cm^2 for unflaked sorghum grain; flaking the cooked grain increased gas production still further. They suggested that pressure cooked grain should be flaked if optimum utilization is to be expected. Also, Trei *et al.* (1970) found gas production to be greater when barley was used as the substrate rather than sorghum grain. Frederick, Theurer and Hale (1968) suggested that combination of heat, moisture, and pressure involved in steam flaking increased the susceptibility of starch granules in the sorghum grain to enzymatic attack. Liang *et al.* (1970) reported that the susceptibility of corn and sorghum starch to enzymatic attack increased as pressure was increased by increments from 1.8 to 6.0 kg/cm^2. Lengthening cooking time from one to 10 minutes was beneficial when small amounts of water were added to the grain but had no effect or was detrimental at higher moisture levels. There was a sharp decrease in corn and sorghum grain starch digestibility when the amount of water added before cooking was increased above 16% with a 10 minute cooking time. The same decrease occurred above 18% added moisture when cooking time was only one minute.

Reconstituting

Recently, much interest has been directed toward reconstituting (adding water back to dry grain) and high moisture harvesting of sorghum grain. Many researchers (Parrett and Riggs, 1967; McGinty, Pennic and

Bowers, 1968; Newsom et al., 1968; Totusek, 1969; White and Totusek, 1969; White et al., 1969b; Wagner and Schneider, 1970; Martin et al., 1971; Wagner, Christiansen and Holloway, 1971) have indicated improvements of about 6 to 10% in feed efficiency of beef steers fed reconstituted and high moisture harvested grain as compared to dry rolled or finely ground grain. Both reconstituting and high moisture harvesting of the grain result in improved digestibility over dry rolled or coarse ground sorghum grain (McGinty, Breuer and Riggs, 1967; Buchanan-Smith et al., 1968). Martin et al. (1970) observed that high moisture harvested shelled corn was utilized 11.9 % more efficiently than dry shelled corn.

Wagner and Schneider (1970) concluded that whole sorghum grain reconstituted to a moisture level of 30 % should be stored for a minimum of 20 days to obtain the desired improvement in feed efficiency. Wagner et al. (1971) suggested that the time for reconstituting may be shortened from the 20 day period if the moisture level is increased above 30 %, but moisture levels over 30 % were deemed questionable because of difficulties associated with achieving moisture contents as high as 38 or 40 % when reconstituting sorghum grain.

Newsom et al. (1968) found that reconstituted rolled sorghum grain was superior to reconstituted ground sorghum grain in terms of improved feed efficiency. White et al. (1969a) concluded that reconstituted sorghum grain must be stored in the whole form to obtain increased utilization. It is suggestive that the changes which occur during reconstituting are similar to those of germination. There appears to be an essential link between the embryo and the seed coat in transporting gibberellic acid to the aleurone layer in order to synthesize a specific amylase enzyme (van Overbeek, 1966). Microscopic studies of the physical changes in reconstituted grain, revealed non-distinct, poorly defined cell walls in reconstituted grain as compared to sharp, well defined cell walls in the air-dry grain (Florance, Riggs and Potter, 1968). Evidence of a destroyed proteinaceous matrix surrounding the starch granules was exhibited by the presence of a large number of free starch granules in reconstituted grain.

Other Processing Methods

Alego *et al.* (1968) found exploded sorghum grain to be equal to steam rolled grain in terms of the performance of fattening beef steers. Riggs *et al.* (1970) reported that feeding sorghum grain popped to various degrees resulted in significantly reduced feed intake as compared to nonheated, dry rolled grain, but the reduced feed intake was accompanied by increased feed efficiency. They noted a lower acetic to propionic acid ratio which was commensurate with greater feed efficiency. No differences in digestibility were found among cattle fed the heat treated fractions, indicating that dry heat rather than popping *per se* was responsible for the changes in performance. DeBie and Woods (1964) reported that steers receiving 80% expanded corn in a mixed ration gained less and consumed less feed than those fed rations containing cracked corn. Enzyme supplementation to the expanded corn rations resulted in a 3.8% increase in gain. Pope, Harper and Waller (1963) found no advantage due to pressure cooking and expanding sorghum grain in terms of the performance of beef steers. Similarly, Bush *et al.* (1964) found no advantage for expanded and subsequently ground (3/64 inch screen) sorghum grain for dairy cows in comparison to grain finely ground only (3/64 inch screen).

Physiologic Responses in Relation to Grain Intake and Preparation

Limits on Grain Intake by Cows

The method of grain preparation may be especially important in relation to feeding dairy cows because of relatively high total feed intakes during the lactation. It is generally conceded that high-level concentrate feeding usually results in increases in milk production, mainly due to greater intake of energy. However, unlimited grain feeding does not always increase production and may, in fact, be detrimental to the cow. Kesler and Spahr (1964) concluded that dietary fiber levels below 13 to 14% of the dry matter may be detrimental to the lactating animal and that maximum energy intake is reached when concentrates make up 50 to 60% of the total dry matter consumed. Zeremski _et al_. (1965) observed that rations containing up to 72% concentrates on a dry matter basis were able to sustain a normal fat test in the milk. They noted a significant increase in non-fat solids with increasing proportions of concentrate in the ration. In contrast, Ronning and Laben (1966) reported that a 60:40 ratio of hay to concentrate in a milled diet fed free choice to lactating cows resulted in the best overall performance. On a high roughage diet cows were unable to consume sufficient energy and the percentage of fat in milk from cows on an all concentrate ration was depressed markedly. Wagner and Loosli (1967) found decreases in digestibility when increasing amounts of the same ration were fed, but the degree of depression per unit of intake (multiple of the maintenance requirement) was greater as the percentage of concentrate in the ration increased. McCaffree and Merrill (1968) found grain dry matter intake was maximal and forage dry matter intake minimal during the fifth week of the lactation period under conditions of essentially free-choice consumption. The maximal energy intake occurred when the concentrate comprised about 63% of the dry matter of the ration. Moreover, Swanson, Hinton and Miles (1967) found that cows fed a diet averaging 67.6% concentrate during a complete lactation utilized dietary energy less efficiently than cows fed a diet which averaged 51.1% concentrates. Restricting roughage and substituting concentrate for roughage TDN for cows liberally fed concentrates gave no benefits and resulted in lower milk fat tests and efficiency. In a summarization of several other experiments, Baumgardt (1967) concluded that for rations containing 40 to 60% grain the gross efficiency (milk energy ÷ digestible energy) of dairy cows was about 33.5% and when the ration contained 80% grain the gross efficiency dropped to 26.0%.

The types of rations commensurate with optimum response of lactating dairy cows are not the same as those fed to fattening beef cattle. Approximately 50 to 60% concentrate in a dairy ration is the maximal level for maximal energy intake and milk composition compatible with the present market.

Sites of Starch Digestion

Recently, much interest has developed in determining the site of digestion of starch in processed grains. There is evidence suggesting that both cattle and sheep can completely digest the starch contained in certain cereal-based diets, but there are differences among grains and processing methods as to the site of digestion (Armstrong and Beever, 1969).

Karr, Little and Mitchell (1966) and Tucker, Mitchell and Little (1968) observed that when sheep and cattle were fed rations containing 20 to 80% ground maize 16 to 35% of the starch was digested in the intestines, caecum and colon. This is not in complete agreement with the results of other workers (Sutton and Nicholson, 1968; MacRae and Armstrong, 1969; Topps, Kay and Goodall, 1968a; Topps et al., 1968b) who reported that diets of pelleted, rolled, or whole barley, dairy cubes, or dairy cubes plus flaked maize all resulted in only 4 to 10% of the starch being digested in the intestines.

Armstrong and Beever (1969) concluded that certain cereal-based diets fell into two categories with regard to sites of digestion of starch. When the cereal component was barley or flaked maize, the amount of starch entering the small intestine of the sheep was about 8% of the total ingested, and this part was almost completely digested in its passage through the small intestine. For diets containing ground maize, the amount of starch passing the pylorus of cattle was about 32% of that ingested, and the major part of this portion was apparently digested in the small intestine.

The results obtained by MacRae and Armstrong (1969) with sheep fed whole or rolled barley suggest that its digestive system can handle either form of this grain with equal effectiveness. Buchanan-Smith et al. (1968) reported that apparent starch digestibility by cattle and sheep fed coarse ground, fine ground, steam processed and rolled, and reconstituted and rolled sorghum grain was in the range of 91 to 95%. Sheep and cattle did not differ in digestibility of reconstituted and steam processed sorghum grain; however, sheep apparently digested ground sorghum grain better than cattle.

Holmes *et al.* (1971) found that overall starch digestibility of sorghum grain steam processed for 8 minutes at atmospheric pressure and sorghum grain steam processed for 1.5 minutes at 3.5 kg/cm^2 was about 97% for both cattle and sheep. There appeared to be less starch in the abomasum with sorghum grain steam processed at 3.5 kg/cm^2 as compared to that processed under atmospheric pressure. The concentrations of starch in the abomasal contents of sheep and cattle fed atmospheric processed sorghum grain were 28.2 and 16.5%, respectively, and for sorghum grain processed at 3.5 kg/cm^2 the values were 14.8 and 7.7%, respectively.

McNeill (1970) reported that the apparent digestibility of starch in sorghum grain processed by different methods (dry ground, reconstituted and ground, steam flaked, and micronized) was within the range of 97 to 100%. The extent of ruminal digestion was highly dependent upon the method of processing. The extent of ruminal digestion of starch was reported as follows: dry ground (5/16 inch screen), 42%; reconstituted and ground (5/16 inch screen), 67%; steam flaked, 83%; and micronized, 43%. Starch in the dry ground and micronized treatments apparently was not as susceptible to rumen microbial digestion and thereby an appreciable amount was digested in the intestines. These observation are in agreement with the work reported by Tucker *et al.* (1968). In the above studies no distinction was made between starch of feed origin that escaped fermentation in the reticulo-rumen and that of microbial origin, particularly protozoal, which may have been produced within the rumen and subsequently entered the lower part of the alimentary tract.

The enzymes involved in the digestion of starch in the small intestine are the amylases and maltases of pancreatic juice and the amylase, maltase and oligo-1:6 glucosidase of intestinal mucosa. Armstrong and Beever (1969) reported the pH opima for α amylase from pig pancreatic juice to be 6.9, maltase of calf intestinal mucosa to be 6.8-7.0, and oligo-1:6-glucosidase to be 6.2-6.4. The pH range found in digesta passing the pylorus on hay plus barley diets lies between 2.6-3.5 and at the ileum 8.0-8.3. In sheep fed grass cubes the pH at the start of the jejunum was 2.5-4.0, at the end of the upper jejunum 3.9-5.0 and at the end of the jejunum 7.2-7.9. It would, therefore, seem reasonable to suppose that maximal hydrolysis of starch to glucose would occur in the proximal half of the jejunum, and Armstrong and Beever (1969) noted that activities of intestinal amylase and maltase were highest in the jejunum as compared to the activities in the duodenum and ileum.

Relation of Rumen VFA to Milk Yield and Composition

A number of workers (Balch et al., 1955a; Coppock, Flatt and Moore, 1964; Shaw et al., 1960; Tyznik and Allen, 1951; and Shaw et al., 1959) have shown that the proportion of VFA in the rumen varies with the nature of the diet. A flaked maize ration resulted in a lower concentration of acetic acid and greater concentrations of propionic and lactic acid in the rumen (Phillipson, 1952). When cows were fed 1 kg hay and 4 or 5 kg flaked maize once daily Sutton (1969) found the proportions of VFA in the rumen to vary widely but on the average acetic acid constituted about 52%, propionic acid about 29% and n-butyric acid about 13% of the total VFA. Along with the type of diet, ration preparation also influences changes in the ruminal VFA. Shaw et al. (1960) observed that grinding and pelleting the hay along with steam heated and flaked corn resulted in a marked decrease in the molar proportion of rumen acetate and an equally marked increase in the molar proportion of rumen propionate. Riggs et al. (1970) noted that steers fed heat treated (popped) sorghum grain resulted in a decreased molar proportion of acetate and an increased molar proportion of propionate. Brown et al. (1970) reported overall molar percentages of acetate and propionate to be 38 and 29%, respectively, for combinations of barley and sorghum grain either pelleted or steam processed in which the concentrate comprised 45% of the total ration. The observed differences in rumen fermentation patterns are very likely associated with the availability of the substrate. Holmes et al. (1971) observed bacterial adaptation to different steam processed rations as evidenced in vitro by the increased ability of rumen flora to ferment the ration with the more available substrate.

The relationship between the fat content of milk and the proportion of rumen VFA has been documented by many workers (e.g., Emery, Brown and Thomas, 1964; Schultz, Jorgensen and Pendleton, 1965; McCullough, 1966; Baumgardt, 1967; Davis, 1967; Storry and Rook, 1966). The possibility of attaining more efficient milk production through the use of diets which change the proportions of rumen VFA within certain limits is supported by the observations of Elliot and Loosli (1959) and Coppock et al. (1964). Within the range of about 75 to 60 molar percent of acetic acid in the rumen fluid, the net efficiency of milk production was found to increase as the percent of acetic acid decreased. However, further decline in molar percentage of rumen acetic acid is associated with a marked decline in milk fat test and gross efficiency of milk production (Baumgardt, 1967). Orskov et al. (1969) reported that no differences were detected in the utilization of the energy of acetic and propionic acids but there were differences in the partition of energy into milk or body tissues; with acetic acid infusion more energy was secreted as milk and with propionic acid infusion more was deposited in body tissue. The basal ration consisted of a pelleted mixture of 20% lucerne hay and 80% concentrates. They noted an increase in milk fat percentage with acetic acid infusion, but not complete recovery to normal. It was suggested that the low percentages of milk fat found when cows are given concentrates could result from a decreased extent of fermentation in the rumen, allowing a greater proportion of the starch consumed to be absorbed as glucose in the small intestine. It has been suggested (Van Soest, 1963) that digestion and absorption of starch in the small intestine may be as effective in depressing the fat content of cow's milk as production and absorption of propionic acid in the rumen. Orskov et al. (1969) concluded that any factors which reduce the rate of fermentation or increase the rate of passage of concentrate diets are likely to decrease the yield of milk fat while factors which have the converse effects will increase it.

Shaw (1959) suggested that the non-fat solids of milk may be produced more efficiently with rations which alter the rumen VFA sufficiently to reduce the fat content of milk, and some data were reported by Shaw et al. (1959) in which such an increase in efficiency was indicated. Balch et al. (1954) and Balch et al. (1955a) observed that the non-fat solids content of milk increased as milk fat percentage declined. However, in other work (Balch et al., 1955b) cows fed a fat-depressing diet produced less milk with no change in percentage of non-fat solids.

It is generally conceded that 60% concentrates in the ration is the maximal level commensurate with ruminal VFA production associated with normal milk fat percentage (Ronning and Laben, 1966; Baumgardt, 1967; Swanson et al., 1967; McCaffree and Merrill, 1968; Villavicencio et al., 1968). Moreover, maximum energy intake, expressed in total digestible nutrients (TDN) has been observed at the point where concentrates comprise about 50-60% of the ration (Kessler and Spahr, 1964; Wagner and Loosli, 1967; McCaffree and Merrill, 1968). Expressed in terms of estimated net energy (ENE) values, which may be a more meaningful measure of the energy available for productive purposes, the point of maximal energy intake is at about 65% concentrates (Zeremski et al., 1965).

CHAPTER III

EXPERIMENTAL PROCEDURE

Experimental Design

Thirty six Holstein and Ayrshire cows (30 Holsteins and 6 Ayrshires) were divided into blocks of three based upon breed, season of calving, lactation number and initial milk production.

A 3 x 3 rotational (Latin square) design was used. All cows were placed on a 2-week standardization period 5 to 6 weeks after calving. The respective members of each trio were randomly assigned to one of three ration treatments at the end of the standardization period.

Comparison periods, each 6 weeks in length, were used. The data on milk production and composition were used from only the last 4 weeks of each comparison period. Cows began the first comparison period approximately 8 weeks after calving, which was assumed to be near the peak of the lactation cycle. The ration treatments in the following comparison periods for each cow were then assigned in sequence according to the experimental design (Table I).

Ration Preparation

The experimental ration fed comprised a 50:50 ratio of baled alfalfa and concentrate mixture (Table II). The only variable in the concentrate mixture was the particle size of the ground sorghum grain. Yellow endosperm hybrid sorghum grain (NK222) grown at the Fort Reno Research Sta-

TABLE I

EXPERIMENTAL DESIGN

Comparison Period	Cow[a]		
	A	B	C
1	C	M	VF
2	M	VF	C
3	VF	C	M

[a]Ration treatments: C = coarse; M = medium, VF = very fine

TABLE II

INGREDIENT COMPOSITION OF CONCENTRATE MIXTURE

Ingredient	Percent
Sorghum grain, ground	70
Soybean oil meal, 44%	10
Wheat middlings	10
Dried molasses	7
Beet pulp	1
Dicalcium phosphate	1
Trace mineral salt	1

tion was purchased and stored prior to initiation of the experiment. The grain was ground with a Model No. 40 Fairbanks-Morse hammermill. The remaining concentrate ingredients were purchased and stored prior to the experiment. During the first half of the experiment the concentrate mixture was mixed and sacked into 45.4 kg bags and labeled by the Stillwater Milling Company, Stillwater, Oklahoma. During the second half of the experiment the concentrate was mixed at the Oklahoma State University dairy barn and stored in bulk bins. Grinding and mixing were conducted and supervised by the author. Each bin was labeled with a designated color to facilitate proper identification by the farm personnel.

Feeding and Management of the Cows

During the initial 2-week standardization period the animals were adjusted to the concentrate mixture (Table II) with the sorghum grain very finely ground. During this period, the cows were fed to maximal consumption with the ratio of concentrate to hay (alfalfa, baled) approximately 50:50. Feed allowances were calculated on the basis of size, age, milk production and milk fat percentage. Production was averaged over the last 5 days of the standardization period and the fat test was the average of the 2 weekly tests during this period. The concentrate was calculated to contain 69% TDN and the hay was estimated to contain 52% TDN, resulting in an estimated 61% TDN for the total ration. The ration allowances were calculated according to requirements indicated by Moe, Reid and Tyrrell (1965). Thus, the maintenance requirement of a 454 kg mature animal was assumed to be 3.178 kg TDN per day, with the requirements of animals of other body weights assumed to be proportional (X kg TDN/3.178 kg TDN = Wkg 0.73/454 kg 0.73 where x = maintenance requirement; w = weight of cow) to body weight raised to the 0.73 power. The maintenance allowance for first calf heifers was the 1966 NRC requirement for growth of animals of comparable weight, and the allowance for second lactation animals was the average of the requirements for growth and maintenance of mature animals. The allowance for production was based on fat corrected milk (FCM) yield assuming a depression in TDN of 3% per maintenance-intake unit (Moe et al., 1965). Feed allowances were reduced by 10% of the original allotment at the beginning of each of the two remaining 6-week comparison periods. To ensure a constant 50:50 ratio of concentrate to hay intake during the course of the experiment the allowance was reduced an appropriate amount if more than 10% of either hay or concentrate was refused for 2 consecutive days. Feeding of the original allotment was resumed as soon as the cow was able to consume that amount.

The cows were milked twice daily; at 6 a.m. and 5 p.m. They were kept in two outside lots during the day. At 1 p.m. the cows were placed in individual tie stalls in a loafing barn adjacent to the lots to eat their daily allotment of hay. At the end of 3 hours they were turned out into the lots. Any cows that did not consume the entire allotment of hay in the afternoon were returned to the stalls in the morning at 8 a.m. for an opportunity to consume the remaining portion. One-half of the concentrate allotment was fed 1 hour prior to each milking in a stanchion barn with separate feeding stalls. Water was available to the animals in the stanchion barn and in the lots. Block salt was available to the animals in the lots. Orts of hay and grain were weighed back once daily after the morning feeding. Treatment for mastitis or other injuries was carried out as needed.

Data Collection

Each time sorghum grain was ground a representative sample was taken from each treatment batch of ground grain for determination of particle size (Table III). A standard method approved by the American Dairy Science Association in 1969 (Ensor, Olson and Colenbrander, 1970) was used for determining and expressing fineness of feed materials by sieving. Representative samples were taken from each batch of concentrate mixture and stored in a freezer for later analysis.

Representative samples of alfalfa hay were taken using a Penn. State hay sampler. After mixing, a hand grab sample was taken from the quantity of hay obtained from sampling. The hay and concentrate samples were ground in a Wiley Mill with a 1 mm screen. Determinations of dry matter, crude protein, ether extract, starch and nonstarch carbohydrate were determined (Table IV). Starch was determined according to a modified procedure of Hassid and Neufeld (1964).

Apparent digestibilities of the nutrient components were determined by using chromic oxide as an external indicator. Chromic oxide was administered to one-half of the cows during the last 12 days of each comparison period. Fifteen grams of powdered chromic oxide were mixed by hand with the concentrate allotment for each cow just before each feeding. There were no observable refusals of chromic oxide or chromic oxide sticking to the sides of the manger. "Hand grab" fecal samples were collected twice daily at 8:30 a.m. and 4:30 p.m. during the last 5 days of the comparison period. The fecal samples were dried at 95 C in an oven for 48 hours. Later they were ground in a Wiley Mill with a 1 mm screen. Fecal samples were ashed in silica crucibles for 3 hours at 550 C. The chromium concentration was determined as described by

TABLE III

PARTICLE SIZE DISTRIBUTION OF SORGHUM GRAIN

GROUND TO DIFFERENT DEGREES OF FINENESS

Sieve Diameter (microns)	U.S. Standard Sieve No.	Percent Retained on Screen		
		Coarse	Medium	Very Fine
2000	10	1.5	0.4	0.0
1000	18	32.8	28.3	1.7
500	35	38.7	40.2	35.9
250	60	13.3	15.7	28.9
125	120	6.4	7.2	15.5
pan		7.3	8.2	18.0
Geometric mean Diameter (microns) Dgw		641	584	315
Geometric Standard deviation Sgw		2.36	2.36	2.32

TABLE IV

CHEMICAL ANALYSIS OF RATION COMPONENTS

Item	Alfalfa hay	Concentrate Mixture
	%	
Dry matter	89	89
Crude protein	19	14
Ether extract	3	3
Ash	8	5
Starch	0	66
Non-starch carbohydrate	70	12

Williams, David and Iismaa (1962) using a Bausch and Lomb AC 2-20 atomic absorption flame spectrophotometer. Adjustments were made for diurnal variations in excretion of chromic oxide on the basis of a 24 hour excretion curve determined by collecting fecal samples from 3 cows at 2-hour intervals. The apparent digestibility was calculated as follows:

$$\text{Apparent digestibility of nutrient (\%)} = 100 - \left[100 \times \frac{\%\ \text{indicator in feed}}{\%\ \text{indicator in feces}} \times \frac{\%\ \text{nutrient in feces}}{\%\ \text{nutrient in feed}}\right]$$

Rumen samples were collected from each cow with a stomach tube on the last day of each comparison period at 2, 4 and 6 hours after the morning grain feeding. Rumen microflora were killed by adding 0.5 ml saturated mercuric chloride per 50 ml rumen fluid. The samples were prepared for analysis of VFA as described by Erwin, Marco and Emery (1961).

An Aerograph, Model 600-D, gas chromatograph was used for the VFA analysis. The column material consisted of neopentyl-glycol succinate (20% NPGS on 60/80 firebrick treated with 3% H_3PO_4). A VFA standard solution (Table V) similar in concentration and molar percentage to that found in the rumen fluid was prepared for use in the quantative determination of the individual acids found in the rumen fluid samples. The VFA were expressed as millimoles per 100 ml and as molar percentage of the total concentration.

Milk production was recorded twice daily. Individual milk samples were obtained at four consecutive milkings beginning with Monday p.m. of each week. These four samples were composited in proportion to the cow's milk yield corresponding with each sample. Total solids were determined by placing 3 ml of milk in an aluminum dish and drying for 4 hours at 100 C in a forced air oven. Milk fat was determined according to the Babcock

TABLE V

STANDARD VFA SOLUTION USED IN DETERMINING RUMEN VFA CONCENTRATIONS

Acid	g/liter	mmoles/100 ml	Molar Percent
Acetic	4.5724	9.1366	58.79
Propionic	2.3273	3.7699	24.26
N-butyric	1.7752	2.4178	15.56
N-valeric	0.1851	0.2176	1.40

procedure.

The body weight of each cow was recorded on 3 consecutive days after the p.m. milking during the last week of the standardization period and during the last 3 days of each of the three comparison periods.

CHAPTER IV

RESULTS AND DISCUSSION

Feed Intake and Ration Digestibility

The cows were fed a 50:50 ratio of hay to concentrate during the course of the experiment. A feed allowance for growth was considered for first and second lactation animals. Nearly complete consumption of the calculated allotments was obtained by all cows on the three ration treatments. Slightly more grain than hay dry matter was consumed (Table VI). The small amount of hay refused usually consisted of a few coarse stems or pieces of moldy material. Several cows required 1 or 2 days to adjust to the very finely ground grain, otherwise, the animals readily consumed the concentrate mixtures during the comparison periods. Some cows appeared to drink a considerable amount of water near the end of the grain feeding period. A few of the cows receiving 10 kg or more hay per day required a second feeding period. They usually consumed the remainder in the morning. During the warm summer months some of the cows preferred to consume the majority of their hay in the morning.

The calculated feed allotments were sufficient to sustain an increase in body weight while on experiment (Table XI in the Appendix). The very finely ground sorghum grain resulted in a body weight gain of 15.5 kg as compared to 11.9 kg and 5.9 kg for the medium and coarse ground grains, respectively (Table VI). This would suggest that the very finely ground grain provided more energy for body gain. A small portion

TABLE VI

AVERAGE FEED INTAKE AND BODY WEIGHT CHANGE

Item	Ration Treatment		
	Coarse	Medium	Very Fine
Concentrate dry matter intake (kg/day)	8.90	9.05	9.07
Hay dry matter intake (kg/day)	8.89	8.98	8.99
Body weight gain (kg/6 weeks)	5.9	11.9	15.5

of the increased body weight gain may be accounted for by a slightly greater consumption of hay and concentrates by the cows fed the very finely ground grain as compared to the other processing methods. Assuming the energy value of the weight gain to be about 7 Mcal ME per kg of weight gain (Reid and Robb, 1971), the additional feed intake by the cows fed the very finely ground grain would only account for 1 kg of the body weight gain by the cows fed the very finely ground sorghum grain.

McNeill (1970) reported that the extent of ruminal digestion of starch was greater for sorghum grain steam flaked or reconstituted and ground than for grain micronized or dry ground. Therefore, more of the very finely ground grain may have been digested in the rumen as compared to the medium and coarse ground grain, however, additional work is needed to determine the site of starch digestion with respect to particle size of the grain.

There was no problem with the palatibility of the very finely ground sorghum grain and this was evidenced by the greater intake of concentrate (Table VI) as compared to the other ration treatments. In contrast, Olson (1942) reported that cows preferred coarsely ground corn and oats to finely ground corn and oats.

In this study it became quite apparent that the geometric mean diameter of ground sorghum grain was dependent upon a combination of several variables. The hammermill screen size was not an accurate determinant of the fineness of grain produced. As shown in Figure 1, the size of the coarse ground and medium ground grain was not very different even though the hammermill screen sizes for the coarse and medium ground grain were 3/4 and 1/4 inch, respectively. Other variables influencing the fineness of the grain are the size and type of hammermill, the moisture in the grain and the rate of flow of the grain through the hammermill. Therefore, it is easily conceivable that two identical screen sizes could produce a ground grain containing different particle sizes.

The apparent digestibility coefficients of the ration components are given in Table VII. There was no statistically significant difference ($P > .05$) between the apparent digestibilities of dry matter, crude protein, ether extract and nonstarch carbohydrate for the different ration treatments. There was a small but nonetheless significant ($P < .05$) improvement in starch digestibility in favor of the very finely ground grain. Since the total ration contained 35% sorghum grain it is not very likely that an improvement of starch digestibility would be reflected in dry matter digestibility. The observed apparent starch digestibility of 96 to 98% is similar to values reported by other workers (McNeill, 1970; Tucker _et al._, 1968; Karr _et al._, 1966, and Holmes _et al._, 1970). However, when fine and coarse ground sorghum grain made up 76% of the ration Buchanan-Smith _et al._ (1968) reported apparent starch digestibilities by beef cattle to be 91 and 92% respectively. Wagner and Looslie (1967) found that the digestibility of a ration decreased as the level

TABLE VII

APPARENT DIGESTIBILITY COEFFICIENTS OF RATION COMPONENTS

Component	Ration Treatment		
	Coarse	Medium	Very Fine
	%		
Dry matter	67.6	69.5	68.8
Crude protein	65.8	67.1	65.3
Ether extract	61.7	63.6	65.1
Starch	96.4[ab]	96.3[a]	98.1[b]
Non-starch carbohydrate	51.4	54.9	53.6

[ab]Means with different letters are significantly different ($P < .05$) according to Duncan's multiple range test (Steel and Torrie, 1960).

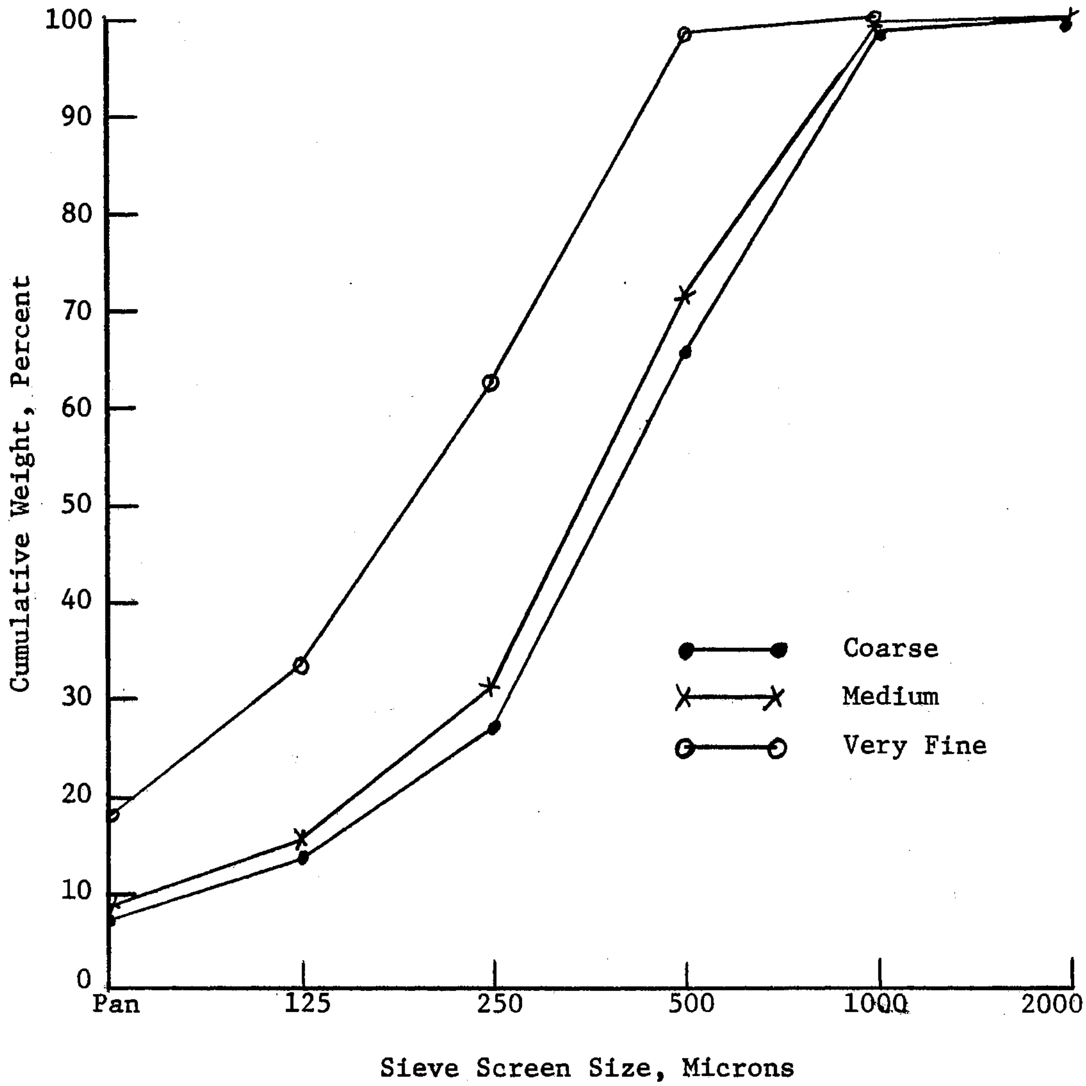

Figure 1. Cumulative Particle Size Distribution of Ground Sorghum Grain

of intake increased and as the level of concentrates increased for lactating dairy cows. The comparisons of grain processing methods between dairy and beef cattle need to be interpreted with care since a lactating dairy cow easily consumes twice as much dry matter as a beef steer and most dairy rations contain a lower level of grain in the total ration. Armstrong and Beever (1969) stated that in most of the experiments no distinction has been made between fecal starch of feed origin and fecal starch of microbial origin. Also, there are several different methods available to measure starch but Armstrong and Beever (1969) concluded that the anthrone procedure gave comparable results to those determined using the enzymatic procedure.

Rumen VFA Characteristics

Molar percentages of rumen VFA were similar for all ration treatments (Table VIII), except at 2 hours after feeding the molar percentages of acetate and propionate were significantly different ($P < .05$). The acetate proportion was lower and the propionate proportion was higher for the medium ground ration treatment as compared to the coarsely and finely ground ration treatments. Since the differences were relatively small, they were not considered to be particularly important. There was no consistent trend for C_2/C_3 (acetate/propionate) ratios with respect to time of sampling or ration treatments.

The molar proportions of rumen VFA reported in this experiment (Table VIII) are similar to values reported by Bush et al. (1964) when cows were fed a similar ration containing finely ground sorghum grain.

Elliot and Loosli (1959) reported that the molar percentage of acetic acid declined as the level of concentrate increased; however, molar per-

TABLE VIII

MOLAR PERCENTAGES OF RUMEN VFA

Acids	Hour	Ration Treatment Coarse	Medium	Very Fine
Acetate	2	67.4 [a]	65.8 [b]	67.1 [a]
Propionate		18.4 [a]	20.1 [b]	18.7 [a]
Butyrate		12.7	12.7	12.8
Valerate		1.5	1.5	1.4
C_2/C_3		3.66	3.28	3.58
Acetate	4	66.3	66.2	66.7
Propionate		19.3	19.6	19.0
Butyrate		13.1	12.8	13.0
Valerate		1.4	1.4	1.4
C_2/C_3		3.44	3.39	3.52
Acetate	6	67.1	65.6	66.5
Propionate		18.2	18.9	19.1
Butyrate		13.4	14.2	13.1
Valerate		1.3	1.4	1.4
C_2/C_3		3.70	3.47	3.48

[ab]Means with different letters are significantly different ($P < .05$) according to Duncan's multiple range test.

centages of VFA similar to those in this study were observed when 60% of the estimated net energy came from roughage.

On the other hand, Brown et al. (1970) reported quite a different VFA pattern in cows fed a ration similar in percentage concentrate, i.e. 45%, where the concentrate contained different proportions of pelleted and steam processed milo and barley. Average molar percentages of the various VFA were: acetate, 38; propionate, 29; butyrate, 20; and valerate, 8.

Rumen VFA concentrations (mmoles/100 ml) are given in Table IX. The concentrations of the various acids increased as the particle size of the sorghum grain decreased. This suggests that the very finely ground sorghum grain had more readily available substrate for the microflora to synthesize acids. At 4 hours after feeding the ration treatment effect was most evident in that all the VFA concentrations were significantly greater ($P < .05$) for the very fine ration treatment as compared to the coarsely ground sorghum grain. The greater concentration of rumen VFA as a result of the finely ground sorghum grain would be commensurate with increased starch digestibility and body weight gain as discussed previously. Decreased total concentration of rumen VFA with respect to time after feeding is shown in Figure 2. This was probably a reflection of the absorption of VFA as well as a decrease in the rate of VFA synthesis since the animals had no access to feed during the rumen sampling period. There was a definite trend in the decrease of rumen VFA concentration with respect to periods (Table XIV in the Appendix). This was a reflection of decreased intake of concentrate since the total ration allowance was reduced by 10% in each successive comparison period.

TABLE IX

RUMEN VFA CONCENTRATIONS (MMOLES/100 ML)

Acids	Hour	Ration Treatment		
		Coarse	Medium	Very Fine
Acetate	2	5.51	5.79	6.18
Propionate		1.51[a]	1.81[b]	1.75[ab]
Butyrate		1.05	1.12	1.19
Valerate		0.12	0.13	0.13
Total		8.20	8.85	9.25
Acetate	4	4.86[a]	5.36[ab]	6.07[b]
Propionate		1.39[a]	1.67[b]	1.75[b]
Butyrate		0.96[a]	1.04[ab]	1.18[b]
Valerate		0.10[a]	0.12[b]	0.13[b]
Total		7.31	8.18	9.13
Acetate	6	4.61	4.75	4.95
Propionate		1.26	1.45	1.44
Butyrate		0.93	0.98	0.97
Valerate		0.09	0.10	0.10
Total		6.89	7.29	7.46

[ab]Means with different letters are significantly different ($P < .05$) according to Duncan's multiple range test.

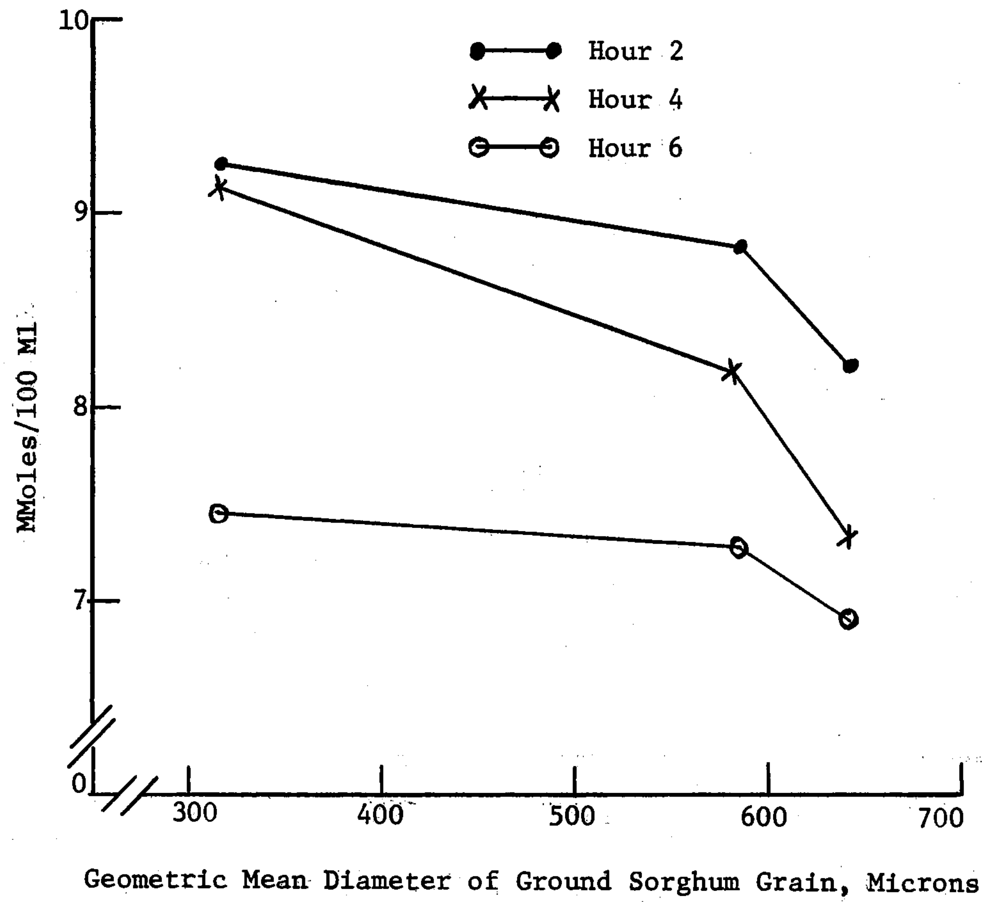

Figure 2. Total Concentration of Rumen VFA in Relation to Particle Size of Ground Sorghum Grain

Milk Yield and Composition

Milk yield was significantly greater ($P < .05$) from the cows fed very finely ground sorghum grain as compared to those fed coarsely ground grain (Table X). As shown in Figure 3, the milk yield increased as the particle size of the ground sorghum grain decreased. Milk fat percentage

TABLE X

AVERAGE DAILY MILK YIELD AND COMPOSITION

Item		Ration Treatment		
		Coarse	Medium	Very Fine
Milk	(kg)	20.60 [a]	20.83 [ab]	21.39 [b]
Milk fat	(kg)	0.681	0.672	0.697
Total solids	(kg)	2.46 [a]	2.48 [a]	2.56 [b]
Milk fat	(%)	3.30	3.25	3.27
Total solids	(%)	11.96	11.96	12.00

[ab]Means with different letters are significantly different ($P < .05$) according to Duncan's multiple range test.

was approximately 3.3 for all three ration treatments. This level was considered adequate for the cows used in this study. The percent total solids was similar for all ration treatments. The decline in milk yield during the periods is shown in Table XV in the Appendix. This decline is a normal part of the lactation cycle. The cause of a decline in milk fat percentage with periods is not known.

The increased milk production, body weight gain and starch digestibility indicate that more energy was available to the animals for productive purposes as a result of fine grinding sorghum grain. Bush *et al.*

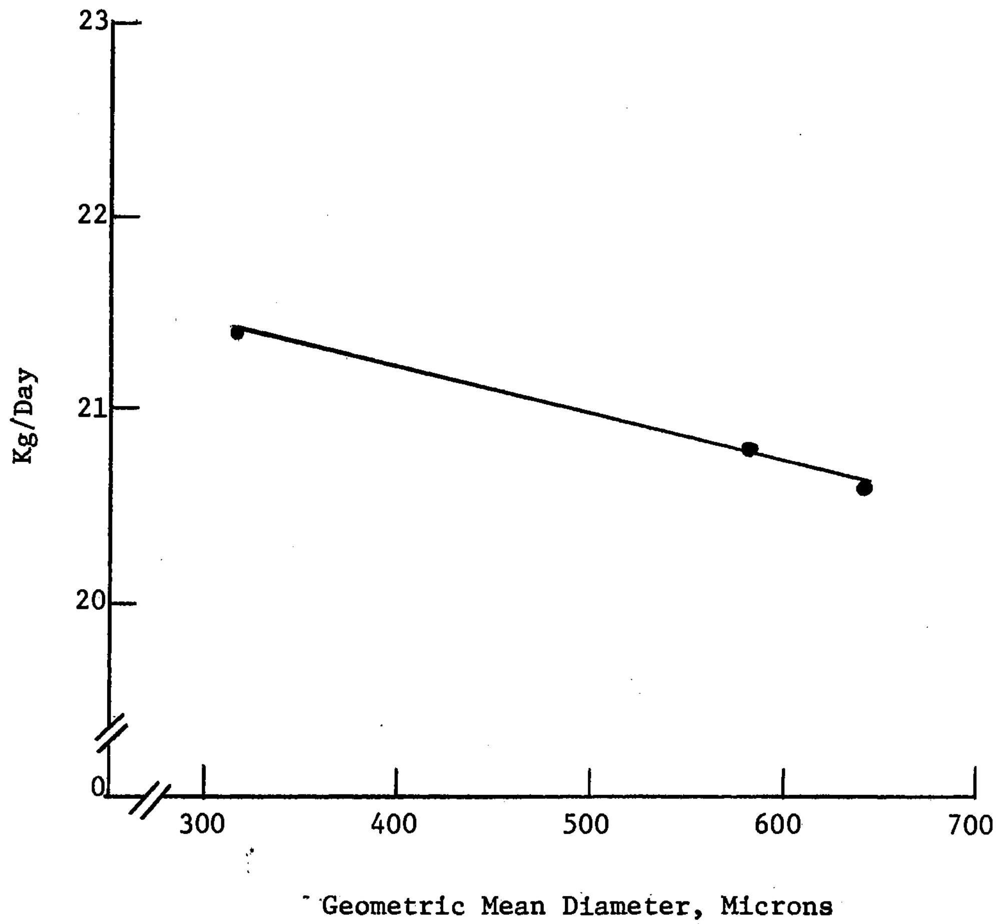

Figure 3. Average Daily Milk Yield in Relation to Fineness of Grinding Sorghum Grain

(1964) found no advantage in terms of milk production response of dairy cows for finely ground (3/64 inch screen) sorghum grain as compared to steam rolled and finely ground or steam rolled, finely ground and dry heated grain; however, they did observe a greater milk production response for finely ground sorghum grain as compared to grain finely ground and partially gelatinized or finely ground and completely gelatinized.

The molar proportions of acetic and propionic acids (approximately 66 and 19%) observed in this study are within the range associated with normal milk fat production by cows (Storry and Rook, 1966). Also, the level of concentrate feeding is within the range suggested by Baumgardt (1967) to attain maximal gross efficiency for production. Brown et al. (1970) observed milk fat percentages of about 3.0 when pelleted and steam processed milo and barley concentrate mixtures comprised 45% of the total ration. This suggests that at these levels (45 - 50%) of concentrate feeding cooking or pelleting the grain lowers the milk fat percentage which is in agreement with other results (Adams and Ward, 1956 and Shaw et al., 1959).

It was concluded that very finely ground sorghum grain resulted in an improved milk production response with no apparent change in the percentages of milk fat or total solids. Additional work is needed to determine the extent of starch digestion of sorghum grain ground to different degrees of fineness along the different portions of the digestive tract. Also, more information is needed concerning the response of lactating dairy cows fed grain processed by some of the other methods such as steam processing and flaking, reconstituting or exploding.

CHAPTER V

SUMMARY AND CONCLUSIONS

This study was undertaken to determine the optimal particle size of processed sorghum grain used in rations for lactating dairy cows. The response criteria were milk yield and composition, body weight changes, nutrient digestibility, postprandial pattern of rumen volatile fatty acid production and general health of the cows.

Thirty-six lactating dairy cows (6 Ayrshires and 30 Holsteins) were divided into blocks of three on the basis of breed, season calving and initial level of milk production. Within blocks, the animals were randomly assigned to treatment sequences of a rotational (Latin square) design involving three ration treatments consisting of coarse, medium and very finely ground sorghum grain. Following a 2-week pretrial standardization period, the experimental rations were fed during three periods of 6 weeks each with the first 2 weeks of each period used as a changeover period.

Cows fed very finely ground sorghum grain produced more milk ($P < .05$) and gained more body weight than cows fed medium or coarsely ground grain. No appreciable differences were detected between ration treatments with respect to percentages milk fat and total solids. Improved starch digestibility and increased concentrations (mmoles/100 ml) of rumen volatile fatty acids were observed when cows were fed the very finely ground grain. There were no appreciable differences in molar percentages of rumen volatile fatty acids that could be explained by ration treatments. Palatability as measured by concentrate consumption was equal for all three ration treatments.

LITERATURE CITED

Adams, H. P. and R. E. Ward. 1956. The value of pelleting the concentrate part of the ration for lactating cattle. J. Dairy Sci. 39:1448.

Alego, J. W., T. P. Brannum, and A. G. Hibbits. 1968. An evaluation of the SYRF high pressure grain-exploding process on milo: Digestibility (nylon bag), VFA (in vitro), steer fattening performance and carcass characteristics. J. Animal Sci. 27:1159. (Abstr.).

Armstrong, D. G. and D. E. Beever. 1969. Post-abomasal digestion of carbohydrate in the adult ruminant. Proc. Nutr. Soc. 28:121.

Atkeson, F. W. and G. H. Beck. 1942. The advantage of grinding atlas sorghum grain for dairy cows. J. Dairy Sci. 25:211.

Balch, C. C., D. A. Balch, S. Bartlett, V. W. Johnson, S. J. Rowland, and J. Turner. 1954. Studies of the secretion of milk of low fat content by cows on diets low in hay and high in concentrates. IV. The effect of variations in the intake of digestible nutrients. J. Dairy Res. 21:305.

Balch, C. C., D. Balch, S. Bartlett, M. P. Bartrum, V. W. Johnson, S. J. Rowland, and J. Turner. 1955a. Studies of the secretion of milk of low fat content by cows on diets low in hay and high in concentrates. VI. The effect on the physical and biochemical processes of the reticulo-rumen. J. Dairy Res. 22:270.

Balch, C. C., D. A. Balch, S. Barlett, Z. D. Hosking, V. W. Johnson, S. J. Rowland, and J. Turner. 1955b. Studies of the secretion of milk of low fat content by cows on diets low in hay and high in concentrates. V. The importance of the type of starch in the concentrates. J. Dairy Res. 22:10.

Baumgardt, B. R. 1967. Efficiency of nutrient utilization for milk production: Nutritional and physiological aspects. J. Animal Sci. 26:1186.

Bishop, S. E., J. K. Loosli, G. W. Trimberger, and K. L. Turk. 1963. Effects of pelleting and varying grain intakes on milk yield and composition. J. Dairy Sci. 46:22.

Brown, W. H., L. M. Sullivan, L. F. Cheatham, Jr., K. J.Halbach, and J. W. Stull. 1970. Steam processing versus pelleting of two ratios of milo and barley for lactating cows. J. Dairy Sci. 53:1448.

Buchanan-Smith, J. G., R. Totusek, and A. D. Tillman. 1968. Effect of methods of processing on digestibility and utilization of grain sorghum by cattle and sheep. J. Animal Sci. 27:525.

Bush, L. J., K. Rauch, P. E. Johnson, and O. C. Griffin. 1964. Effect of different methods of processing sorghum grain on the yield and composition of milk. J. Dairy Sci. 47:344. (Abstr.).

Coppock, C. E., W. P. Flatt, and L. A. Moore. 1964. Relationships between end products of rumen fermentation and utilization of metabolizable energy for milk production. J. Dairy Sci. 47:1359.

Darnell, A. L. and O. C. Copeland. 1936. Ground versus unground grain for lactating dairy cows. Texas Agr. Exp. Sta. Bull. 530.

Davis, C. L. 1967. Acetate production in the rumen of cows fed either control or low-fiber, high-grain diets. J. Dairy Sci. 50:1621.

DeBie, W. H. and W. Woods. 1964. Rumen fermentation and animal performance as influenced by gelatinized corn and enzyme supplementation. J. Animal Sci. 23:872. (Abstr.).

Elliot, J. M. and J. K. Loosli, 1959. Relationship of milk production efficiency to the relative proportions of the rumen volatile fatty acids. J. Dairy Sci. 42:843.

Emery, R. S., L. D. Brown, and J. W. Thomas. 1964. Effect of sodium and calcium carbonates on milk production and composition of milk, blood, and rumen contents of cows fed grain ad libitum with restricted roughage. J. Dairy Sci. 47:1325.

Ensor, W. L., H. H. Olson and V. F. Colenbrander. 1970. A report. Committee on classification of particle size in feedstuffs. J. Dairy Sci. 53:689.

Ensor, W. L., J. C. Shaw and H. F. Tellechea. 1959. Special diets for the production of low fat milk and more efficient gains in body weight. J. Dairy Sci. 42:189.

Erwin, E. S., G. Marco and E. Emery. 1961. Volatile fatty acid analysis of blood and rumen fluid by gas chromatography. J. Dairy Sci. 44:1768.

Fitch, J. B. and F. B. Wolberg. 1934. The utilization of atlas and Kansas orange sorgo seed by dairy cows. J. Dairy Sci. 17:343.

Florance, H. D., J. K. Riggs, and G. D. Potter. 1968. Physical characteristics of reconstituted sorghum grain. J. Animal Sci. 27:1163. (Abstr.).

Fountaine, C. and E. E. Bartley. 1962. Personal communication. Kansas State University.

Frederick, H. M., B. Theurer, and W. H. Hale. 1968. Effect of moisture, heat, and pressure on in vitro starch digestion of milo and barley. J. Animal Sci. 27:1110. (Abstr.).

Garrett, W. N. 1965. Comparative feeding value of steam-rolled or ground barley and milo for feedlot cattle. J. Animal Sci. 24:726.

Garrett, W. N., G. P. Lofgreen, and R. L. Hull. 1968. Steam pressure processed sorghum grain for steers. J. Animal Sci. 27:1164. (Abstr.).

Hale, W. H., L. Cuitun, W. J. Saba, B. Taylor, and B. Theurer. 1966. Effect of steam processing and flaking milo and barley on performance and digestion by steers. J. Animal Sci. 25:392.

Hale, W. H. 1968. Recent findings in grain processing for cattle feeds. Proc. Distillers Feed Research Council. 23:64.

Hassid, W. Z. and E. F. Neufeld. 1964. Whole starches and modified starches. Quantitative determination of starch in plant tissues. IN R. L. Whistler (Ed.) Methods in Carbohydrate Chemistry. Academic Press, New York.

Holmes, J. H. G., M. J. Drennan, and W. N. Garrett. 1971. Digestion of steam-processed milo by ruminants. J. Animal Sci. 31:409.

Husted, W. T., S. Mehen, W. H. Hale, M. Little, and B. Theurer. 1968. Digestibility of milo processed by different methods. J. Animal Sci. 27:531.

Karr, M. R., C. O. Little and G. E. Mitchell, Jr. 1966. Starch disappearance from different segments of the digestive tract of steers. J. Animal Sci. 25:652.

Kesler, E. M. and S. L. Spahr. 1964. Physiological effects of high level concentrate feeding. J. Dairy Sci. 47:1122.

Liang, Y. T., J. L. Morrill, F. R. Anstaett, A. D. Dayton, and H. B. Pfost. 1970. Effect of pressure, moisture, and cooking time on susceptibility of corn or sorghum grain starch to enzyme attack. J. Dairy Sci. 53:336.

MacRae, J. C. and D. G. Armstrong. 1969. Studies on intestinal digestion in the sheep. 2. Digestion of some carbohydrate constituents in hay, cereal and hay-cereal rations. Brit. J. Nutr. 23:377.

Martin, J., R. Peck, M. England, J. Alexander and R. Totusek. 1971. A comparison of corn processing methods, several levels of corn silage, and sorghum stover silage versus corn silage for finishing steers. Okla. Agr. Exp. Sta. Misc. Pub. 85:45.

Martin, J., R. Peck, M. England, J. Alexander and R. Totusek. 1970. Two reconstitution methods and steam flaking for milo with two levels of protein supplementation. Okla. Agr. Exp. Sta. Misc. Pub. 84:41.

McCaffree, J. D. and W. G. Merrill. 1968. Effects of feeding concentrates to maintain body weight of dairy cows in early lactation. J. Dairy Sci. 51:561.

McCroskey, J. E., L. S. Pope, D. F. Stephens, and G. Waller. 1960. Effect of pelleting per se on the utilization of milo and high roughage rations by steer calves. J. Animal Sci. 19:1275. (Abstr.).

McCullough, M. E. 1966. Relationships between rumen fluid volatile fatty acids and milk fat percentage and feed intake. J. Dairy Sci. 49:896.

McGinty, D. D., L. H. Breuer, and J. K. Riggs. 1967. Digestibility of dry and reconstituted sorghum grain by cattle. J. Animal Sci. 26:223. (Abstr.).

McGinty, D. D., P. Penic, and E. J. Bowers. 1968. Moist grain for finishing beef cattle. J. Animal Sci. 27:1170. (Abstr.).

McNeill, J. W. 1970. Factors influencing carbohydrate utilization in steers fed processed sorghum grain. M.S. Thesis. Texas A & M University, College Station, Texas.

McNeill, J. W., G. D. Potter, and J. K. Riggs. 1969. Carbohydrate utilization in steers fed processed sorghum grain. J. Animal Sci. 29:165. (Abstr.).

Mehen, S. M., W. H. Hale, B. Theurer, M. Little, and B. Taylor. 1966. Effect of dry rolling, fine grinding, steam processing and pressure cooking on digestion of milo rations by steers. J. Animal Sci. 25:593.

Moe, P. W., J. T. Reid and H. F. Tyrell. 1965. Effect of level of intake on digestibility of dietary energy by high-producing cows. J. Dairy Sci. 48:1053.

National Research Council, U.S. 1966. Nutrient requirements of dairy cattle. Publ. 1349. Washington, D.C.

Newsom, J. R., R. Totusek, R. Renbarger, E. C. Nelson, L. Franks, V. Newhouse, and W. Basler. 1968. Methods of processing milo for fattening cattle. Okla. Agr. Exp. Sta. Misc. Pub. 80:47.

Olson, T. M. 1942. The effect of fineness of grinding grain on milk production. S. D. Agr. Exp. Sta. Bull. 358.

Ørskov, E. R., W. P. Flatt, P. W. Moe, and A. W. Munson. 1969. The influence of ruminal infusion of volatile fatty acids on milk yield and composition and on energy utilization by lactating cows. Brit. J. Nutr. 23:443.

Osman, H. F., B. Theurer, W. H. Hale and S. M. Mehen. 1970. Influence of grain processing on in vitro enzymatic starch digestion of barley and sorghum grain. J. Nutr. 100:1133.

Parrett, N. A. and J. K. Riggs. 1967. Dry, reconstituted and early harvested sorghum grain for cattle. J. Animal Sci. 26:224. (Abstr.).

Phillipson, A. T. 1952. The fatty acids present in the rumen of lambs fed on a flaked maize ration. Brit. J. Nutr. 6:190.

Pope, L. S., K. Urban, and G. Waller. 1959. Rolling vs. pelleting grains, protein levels and certain feed additives in beef cattle fattening rations. J. Animal Sci. 18:1509. (Abstr.).

Pope, L. S., O. F. Harper, and G. Waller, Jr. 1963. Steam heated (pre-gelatinized) milo for fattening beef calves. Okla. Prog. Rept. MP-70.

Ralston, A. T., D. C. Church, W. H. Kennick, and N. O. Taylor. 1963. Effect of varying milo-barley levels, ration preparation and intraruminal injections of vitamin A upon feedlot performance of steers. J. Animal Sci. 22:943.

Reid, J. T. and J. Robb. 1971. Relationship of body composition to energy intake and energetic efficiency. J. Dairy Sci. 54:553.

Riggs, J. K., J. W. Sorenson, Jr., J. L. Adame and L. M. Schake. 1970. Popped sorghum grain for finishing beef cattle. J. Animal Sci. 30:634.

Ronning, M. and R. C. Laben. 1966. Response of lactating cows to free-choice feeding of milled diets containing from 10 to 100% concentrates. J. Dairy Sci. 49:1080.

Schultz, L. H., N. A. Jorgensen, and R. A. Pendleton. 1965. Effect of addition of sodium bicarbonate to pelleted rations which depress milk fat percentage. J. Dairy Sci. 48:808. (Abstr.).

Shaw, J. C. 1958. Rumen nutrition and intermediary metabolism. Proc. Distillers Feed Conf. 13:74.

Shaw, J. C. 1959. Relationship of digestion end-products to energy economy and milk composition. Okla. Conf. Radioisotopes in Agriculture. USAEC TID-7578. 227.

Shaw, J. C., W. L. Ensor, H. F. Tellechea and S. D. Lee. 1960. Relation of diet to rumen volatile fatty acids, digestibility, efficiency of gain and degree of unsaturation of body fat in steers. J. Nutr. 71:203.

Shaw, J. C., R. R. Robinson, M. E. Senger, S. Lakshmanan, and T. R. Lewis. 1959. Production of low-fat milk. I. Effect of quality and quantity of concentrate on the volatile fatty acids of the rumen and on the composition of the milk. J. Nutr. 69:235.

Smith, E. F., D. B. Parrish, and A. G. Pickett. 1949. Effect of grinding on the nutritive value of grain sorghums for fattening steer calves. Kansas Agr. Exp. Sta. Cir. 250:37.

Smith, E. F. and D. B. Parrish. 1952. A comparison of rolled, coarsely ground and finely ground milo grain for fattening yearling steers. Kan. Agr. Exp. Sta. Cir. 297:49.

Steel, R. G. and J. H. Torrie. 1960. Principles and Procedures of Statistics. McGraw-Hill Book Co., New York.

Storry, J. E., and J. A. F. Rook. 1966. The relationship in the cow between milk-fat secretion and ruminal volatile fatty acids. Brit. J. Nutr. 20:217.

Sutton, J. D. 1969. The fermentation of soluble carbohydrates in rumen contents of cows given diets containing a large proportion of flaked maize. Brit. J. Nutr. 23:567.

Sutton, J. D. and J. W. G. Nicholson. 1968. The digestion of energy and starch along the gastro-intestinal tract of sheep. Proc. Nutr. Soc. 27:49A.

Swanson, E. W., S. A. Hinton, and J. T. Miles. 1967. Full lactation response on restricted vs. ad libitum roughage diets with liberal concentrate feeding. J. Dairy Sci. 50:1147.

Topps, J. H., R. N. B. Kay and E. D. Goodall. 1968a. Digestion of concentrate and of hay diets in the stomach and intestines of ruminants. 1. Sheep. Brit. J. Nutr. 22:261.

Topps, J. H., R. N. B. Kay, E. D. Goodall, F. G. Whitelaw and R. S. Reid. 1968b. Digestion of concentrate and of hay diets in the stomach and intestines of ruminants. 2. Young steers. Brit. J. Nutr. 22:281.

Totusek, R. 1969. Effect of cereal processing on feed efficiency and rate of gain. Oklahoma Cattle Feeders Seminar. Stillwater, Okla.

Trei, J., W. H. Hale and B. Theurer. 1970. Effect of grain processing on in vitro gas production. J. Animal Sci. 30:825.

Tucker, R. E., G. E. Mitchell, Jr., and C. O. Little. 1968. Ruminal and post ruminal starch digestion in sheep. J. Animal Sci. 27:824.

Tyznik, W. and N. N. Allen. 1951. The relation of roughage intake to the fat content of the milk and the level of fatty acids in the rumen. J. Dairy Sci. 34:493. (Abstr.).

van Overbeek, J. 1966. Plant hormones and regulators. Science. 152:721.

Van Soest, P. J. 1963. Ruminant fat metabolism with particular reference to factors affecting low milk fat and feed efficiency. A review. J. Dairy Sci. 46:204.

Villavicencio, E., L. L. Rusoff, R. E. Girouard, and W. H. Waters. 1968. Comparison of complete feed rations to a conventional ration for lactating cows. J. Dairy Sci. 51:1633.

Wagner, D. G., R. Christiansen and W. Holloway. 1971. Influence of storage time and moisture level on feeding value of whole reconstituted milo for fattening cattle. Okla. Agr. Exp. Sta. Misc. Pub. 85:64.

Wagner, D. G. and J. K. Loosli. 1967. Studies on the energy requirements of high-producing dairy cows. Cornell Univ. Memoir 400.

Wagner, D. G. and W. Schneider. 1970. Influence of storage time on feeding value of whole reconstituted milo. Okla. Agr. Exp. Sta. Misc. Pub. 84:28.

Wagner, D. G., W. Schneider, and R. Renbarger. 1970. Influence of steaming time on the nutritive value of steam flaked milo. Okla. Exp. Sta. Misc. Pub. 84:33.

Walker, H. G. 1966. Chemistry of processing grains. 19th Annu. Calif. Anim. Ind. Conf. p. 94.

White, D., J. Newsom, V. Neuhaus, and R. Totusek. 1969a. Grinding milo before versus after reconstitution. Okla. Agr. Exp. Sta. Misc. Pub. 82:39.

White, D., R. Renbarger, J. Newsom, V. Neuhaus, and R. Totusek. 1969b. A comparison of dry and high moisture methods of processing milo. Okla. Agr. Exp. Sta. Misc. Pub. 82:48.

White, D. and R. Totusek. 1969. The effect of moisture level on the feeding value of reconstituted milo. Okla. Agr. Exp. Sta. Misc. Pub. 82:43.

Wilbur, J. W. 1933. Grinding grains for dairy cows. Purdue University Agr. Exp. Sta. Bull. 372.

Williams, C. H., D. J. David and O. Iismaa. 1962. The determination of chromic oxide in faeces samples by atomic absorption spectrophotometry. J. Agric. Sci. 59:381.

Zeremski, D., H. H. Van Horn, A. D. McGilliard, and N. L. Jacobson. 1965. Effect of the net energy concentration of total ration on milk production and composition. J. Dairy Sci. 48:1467.

TABLE XI

DRY MATTER INTAKE AND AVERAGE BODY WEIGHT

Item	Periods 1	2	3
Hay (kg/day)	9.69	9.07	8.11
Concentrate (kg/day)	9.80	9.08	8.14
Body weight (kg)	580	588	595

TABLE XII

AVERAGE BODY WEIGHT CHANGE DURING EXPERIMENT

Ration Treatments	Periods 1	2	3
		kg	
Coarse	10.7	3.1	4.2
Medium	22.8	6.2	6.7
Very fine	16.8	22.3	7.4

TABLE XIII

MOLAR PERCENTAGES OF RUMEN VFA BY PERIODS

Acids	Hour	Periods 1	2	3
Acetate	2	65.5	66.9	67.8
Propionate		19.9	19.2	18.1
Butyrate		13.1	12.5	12.7
Valerate		1.5	1.4	1.5
C_2/C_3		3.29	3.48	3.74
Acetate	4	63.6	67.5	68.1
Propionate		21.2	18.5	18.0
Butyrate		13.7	12.6	12.5
Valerate		1.5	1.4	1.3
C_2/C_3		3.00	3.65	3.78
Acetate	6	65.2	66.4	67.6
Propionate		20.0	18.4	17.7
Butyrate		13.4	13.9	13.4
Valerate		1.4	1.3	1.3
C_2/C_3		3.26	3.61	3.82

TABLE XIV

CONCENTRATION OF RUMEN VFA BY PERIODS (MMOLES/100 ML)

Acids	Hour	Periods 1	2	3
Acetate	2	6.04	5.78	5.66
Propionate		1.90	1.67	1.51
Butyrate		1.20	1.07	1.08
Valerate		0.14	0.12	0.12
Total		9.28	8.64	8.37
Acetate	4	5.52	5.61	5.16
Propionate		1.92	1.54	1.35
Butyrate		1.16	1.05	0.96
Valerate		0.13	0.11	0.10
Total		8.73	8.31	7.57
Acetate	6	4.67	4.81	4.83
Propionate		1.53	1.35	1.26
Butyrate		0.97	0.95	0.97
Valerate		0.10	0.10	0.09
Total		7.27	7.21	7.15

TABLE XV

MILK YIELD AND COMPOSITION BY PERIODS

Component		Periods 1	2	3
Milk	(kg/day)	23.09	20.92	18.80
Milk fat	(kg/day)	0.781	0.675	0.594
Total solids	(kg/day)	2.795	2.502	2.211
Milk fat	(%)	3.39	3.25	3.17
Total solids	(%)	11.96	11.96	12.00

VITA

Barry Jerome Steevens

Candidate for the Degree of

Doctor of Philosophy

Thesis: METHODS OF PROCESSING GRAIN FOR LACTATING DAIRY COWS

Major Field: Animal Nutrition

Biographical:

Personal Data: Born in Owen, Wisconsin, April 25, 1944.

Education: Graduated from Medford High School in 1962; received the Bachelor of Science degree from Wisconsin State University, River Falls in 1966 with a major in Animal Science; received a Master of Science degree from Oklahoma State University in 1968 with a major in Dairy Science; completed requirements for the Doctor of Philosophy degree from Oklahoma State University in July, 1971.

Experience: Raised on a dairy farm in Central Wisconsin, dairy and agronomy projects in 4-H and FFA, 1952-1962; worked in a cheese factory, 1961; worked in a woodworking factory and on a mink ranch, 1962-1966. Research assistant at Oklahoma State University, 1966-1971. National Defense Education Act Fellow, Oklahoma State University, Department of Animal Sciences and Industry, 1967-1970.

Member: Dairy Science Club, Zion Lutheran Church, Alpha Gamma Rho, Toastmasters International, American Dairy Science Association.