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Effect of sorghum grain processing on the performance and metabolism of lactating dairy cows

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EFFECT OF SORGHUM GRAIN PROCESSING ON THE PERFORMANCE AND METABOLISM OF LACTATING DAIRY COWS

by

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As members of the Final Examination Committee, we certify that we have read the dissertation prepared by Jackson Silva e Oliveira

entitled EFFECT OF SORGHUM GRAIN PROCESSING ON THE PERFORMANCE AND METABOLISM OF LACTATING DAIRY COWS

and recommend that it be accepted as fulfilling the dissertation requirement for the Degree of Doctor of Philosophy

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DEDICATION

To my beloved wife Gracinha for her patience and constant encouragement throughout my studies, and to our daughter Bruna for making our life brighter and full of expectations.

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ABSTRACT

Experiments were conducted to compare the effect of processing grain sorghum either by dry rolling or steam flaking on the performance and metabolism of high producing dairy cow.

In an 80 d trial, following a 14 d pretrial for covariance adjustments, 36 Holstein cows divided in 4 groups were fed a total mixed ration (37 forage : 63 concentrate) prepared with one of the following four grains: Steam-rolled corn (CORN), dry-rolled sorghum (DRS), steam-flaked sorghum (SFS) and an equal mixture of DRS and SFS (MIX). Grain comprised 42.2% of diet DM. In the last 14 d of the experimental period a digestibility trial was conducted. There was no difference (PS<.05) in milk, FCM or milk fat production across treatments. Because cows on SFS consumed less DM (P<.05) than those on MIX, the gross efficiency of FCM production was higher (P<.05) for SFS. Other treatments were intermediate for DM intake and FCM efficiency. Milk protein percentage and production were higher (P<.05) for SFS compared to DRS, while lactose and SNF percentages were the highest (P<.05) for SFS compared to other diets. Apparent digestibility of starch from SFS was the highest (P<.01) and that from DRS was the lowest while apparent digestibility of the fiber components and of CP were lower (P<.05) for SFS compared to DRS. Improvement in FCM efficiency and milk protein production was probably due to increased starch degradability.

In a second experiment, the same diets used in the lactation trial were fed to 4 duodenally cannulated cows in a 4 x 4 Latin square design.

Total tract digestibility of starch was higher ($P<.05$) for SFS than MIX and DRS diets and tended to be more digested in the rumen than starch from other diets. Cows fed SFS also tended to more efficiently convert dietary CP digested in the rumen to BCP and to have higher BCP flow to the duodenum. Cows on the SFS diet had highest ($P<.01$) fecal pH, tended to have the lowest amount of fecal protein and the highest apparent digestion of N.

CHAPTER 1

INTRODUCTION

Forage based diets have been used by dairy herds with low or medium production. However, because of genetic improvement, a new kind of dairy cow dominates the U.S. dairy industry. In order to respond with high milk production, these animals need to consume large amounts of energy. Because forage based diets have a low energy density, a change in the diet composition has been necessary.

Because cereal grains have great amounts of energy, they are used to replace part of the forage, and thus increase the energy content of the whole diet.

The non-structural carbohydrates (soluble sugars, starches, frutans, galactans, pectins, etc) of cereal grains play an important role as energy-yielding compounds of the feedstuffs. Starch is the major component of the cereal grains and constitutes one of the high energy-yielding nutrients for ruminants. Many grains, such as corn, barley, oats, wheat and sorghum are used by the dairy industry, but they differ in starch content, starch availability and price.

Because of its adaptation to hot and dry climates, sorghum is abundant in the Southwestern United States. Although having a competitive price and one of the highest starch contents in its grain, the availability of that starch for ruminants is low when fed in the ground or dry rolled forms. However, steam-flaking dramatically improves availability of sorghum starch for ruminants (Theurer, 1986).

Site of starch digestion affects the amount of energy available to the ruminant animal. In the rumen, starch carbon is converted to volatile fatty acids (VFA) and absorbed principally as VFA's. The fermentation of starch in the rumen is accompanied by inevitable losses in heat and methane. In the small intestine (SI), starch is digested enzymatically to glucose which is absorbed into the blood stream. Because of metabolic losses at this site are minimal it has been estimated that starch provides 42% more energy when degraded in SI than in the rumen (Owens et al.,1986).

If the preceding statement is correct, the more starch digested in the small intestine, the more energy will be available to the animal. However, one should not forget that rapidly degradable energy must be available to the microbes in the rumen which perform important digestive functions and supply microbial protein to the animal. So, in order to take advantage of the higher efficiency of starch digestion in the small intestine and to better satisfy the needs of the microorganisms and host, part of the starch might be degraded in the rumen and part in the small intestine. Because different grain processing methods affect site and extent of starch digestion, the proportion of grains in the diet may affect animal performance. At present, there is little solid information on the benefits of starch digestion at each site, particularly in high producing dairy cows.

The objectives of this stud were to determine the effects of dry-rolled sorghum, steam-flaked sorghum and a combination of these grains on:

1) Milk production, milk component yield and efficiency of conversion of feed dry matter to milk in high producing dairy cows, and

2) Partition of starch digestion between the rumen and post-ruminal digestive tract of cows.

CHAPTER 2

LITERATURE REVIEW

Starch.

Starch is the storage polysaccharide of higher plants and a major source of energy for animals. It represents about 60 to 80% of most cereal grains, a large percentage of many roots and tubers and is a major component of many grasses and legumes. The livestock industry depends heavily upon cereal grain as a major source of energy.

Starch is formed by an α-glucosidic chain. Such a compound, yielding only glucose on hydrolysis, is a homopolymer called a glucosan or glucan and composed by two major types of molecules: amylose and amylopectin. A minor component, termed branched amylose, may also be present.

Amylose is a linear polymer of D-glucose units linked by α-1,4 glycosidic bonds. The proportion of amylose in starch ranges from 0 to 80% depending on the plant species and the genetic variation within the species.

Amylopectin is a much larger branched polymer which is the most abundant component of normal starches.It is made by linear chains of α-1,4 linked units of D-glucose with α-1,6 branch points every 20 to 25 glucose residues. Amylopectin comprises 70 to 80% of most cereal starches.

Although starch is composed of glucose units and glucose is water soluble, the material becomes water insoluble as the glucose chain elongates. This insolubility is the result of crystallization occurring at a range of 70 to 150 units of glucose (French, 1973). So, natural starch is difficult or impossible to dissolve in water without the aid of energy (heat) or chemical agents such as aqueous alkali (NaOH or KOH), certain salts ($CaCl_2$, $Ca(NO_3)_2$), amines, amides and polyols. The amylose fraction, due to the regularity of its chain, is very insoluble. However, solubility of starch may be increased by disrupting the normal structure.

Degradability of starch is also known to be affected by the ratio of amylose to amylopectin. The greater the amylose fraction the lower the starch digestibility. No clear explanation has been found for this phenomenon, but it may be related to an amylose- restrictive role in granule swelling and enzymatic hydrolysis (Rooney and Pflugfelder, 1986).

Besides the difference found in starch solubility and degradability due to amylose:amylopectin ratio and chain length, two other important factors, protein bodies and protein matrix, affect the starch utilization by animals. Electron microscopic studies have revealed the presence of protein bodies contained in the mature endosperm of corn, milo, oats and rice grains (Rooney and al.,1983). Those present in corn and sorghum present a low degradability and it was suggested by Delfino (1986) that protein bodies retard enzymatic hydrolysis of starch due to the tight packing of starch granules and protein bodies. Protein bodies of low degradability are particularly abundant throughout sorghum grains.

Starch granules are built on a protein matrix that surrounds the endosperm of all grain. The nature of this matrix affects its digestibility and, consequently, the digestibility of the starch. The matrixes in corn and sorghum are known to be less digestible than those in wheat, barley and oats (Sniffen, 1980). Because starch granules are mostly encapsulated by the protein matrix, the degradation of the starch depends on the degradation of that matrix (Hale, 1973). It was demonstrated by Hahn and al. (1982) that starch degradability of sorghum improved after degrading the protein matrix.

Many processing techniques have been used to improve the starch utilization of sorghum grain by ruminants. Minimal processing such as grinding and dry-rolling results in little improvement because the protein matrix and protein bodies are not affected; although the exposed surface of grain is increased for greater bacterial action, the microbes still do not have easy access to starch granules. In order to disrupt and better expose the starch granule, it is necessary to use heat, moisture and pressure. McNeill et al., (1971) compared the effects of different processing methods on digestibility of sorghum grain and concluded that any method promoting a disruption of the protein matrix increases starch utilization.

Application of heat, moisture and pressure to cereal grains breaks the protein matrix, allowing the starch granule to absorb water, resulting in swelling and finally its rupture. Starch which has been processed by these methods is highly absorbent in water, tends to form a gel and is more susceptible to enzymatic breakdown (Pfost, 1971). The greater the damage to the starch granule the higher the degree of gelatinization.

Sites of starch digestion.

1.Rumen

The major site of starch digestion of sorghum grain by cattle is the rumen, regardless the processing technique utilized. Processing, however, affects the extent of starch digestion at all sites of the digestive tract. In an extensive review Theurer (1986) found that the average ruminal starch degradation of dry-rolled and steam-flaked sorghum for cattle was 57 and 76%, respectively and for the total tract, 91 and 98%. Starch escaping ruminal degradation averaged 43 and 24%. Although based on limited data, this author also found post-ileal starch digestion ranging from 1 to 13% of total starch ingested and starch digestibilities through the ileum averaging 89% for dry-rolled and 96% for steam-flaked sorghum.

Although the main site of starch digestion is the rumen, Orskov (1986) states from experience with barley diets that capacity of the rumen in mature animals to ferment starch when ruminal pH is optimal exceeds the metabolic capacity of the host ruminant to utilize resulting VFAs. Moreover, losses in rumen fermentation amounts to 12 to 20% of the ingested energy, hence it might be beneficial for starch to escape ruminal fermentation in order to avoid fermentation losses.

2.Small intestine

Because increased starch digestion in the small intestine is theoretically beneficial (Waldo, 1973; Orskov, 1986; Owens et al., 1986), many experiments were conducted to study the digestibility of starch at this site. Mayes and Orskov (1974) concluded that for a 30 kg sheep, only

100 to 200 g of starch/day infused in the abomasum is digested in the SI, but if starch is infused in a gelled form, digestive capacity increases to 300 g/day. Moreover, if glucose instead of starch is infused, only 300 to 400 g/day can be absorbed. According to the above authors, limits of glucose absorption place a ceiling on starch digestion in the SI.

In an extensive review, Owens et al. (1986) discussed specific factors suggested to limit intestinal starch digestion. These were: 1)limited activity of amylase, maltase or isomaltase due to inadequate enzyme production, improper pH or presence of enzyme inhibitors (Karr et al., 1966; Clary et al.,1969; Van Ellen et al.,1978; Russell et al.,1981); 2) limited absorption of released glucose from the SI (Ridges and Singleton, 1962; White et al., 1971); 3)insufficient time for complete starch hydrolysis and 4)inadequate access of enzymes to starch granules due to insolubility or impenetrability of the starch granule (Moe et al., 1973; Moe and Tyrrell, 1977). All these factors are discussed and the author concluded that, though limits to digestion in and absorption from the SI can be demonstrated by infusing starch and glucose into the duodenum, enzymatic capacity does not limit intestinal starch digestion, since no plateau in amount of starch disappearing from the small intestine was detected with typical diets. However, extent of starch digestion was incomplete and processing methods which alter the protein matrix increase the extent of starch digestion in both rumen and SI. The same review states that absorption continues to increase as starch supply increases. They reported starch digestibility in the small intestine was 52.9 ± 18.6%, a relatively low and highly variable value. High post-ruminal digestibilities might be attributable to prior exposure of starch to enzymes in the rumen.

Carpenter, quoted by Van Soest (1982), stated that starch digesting capacity in the small intestine of a lactating dairy cow is limited to 1 kg per day. These conclusions come from speculation and extrapolation (from beef and sheep) with little direct evidence.

Herrera-Saldana (1987) reported that post-ruminal starch digestion increased total tract digestion about 49% (from 49% rumen disappearance to 89% for the total tract) when dry-rolled sorghum was the principal grain in diets for lactating dairy cows. Total starch intake was 5.4 kg/day and 2.8 kg/day escaped rumen digestion. About 80% of the by-passed starch disappeared post-ruminally, suggesting that the upper limit for starch digestion in the small intestine is much higher than earlier postulated.

The fate of glucose, resulting from starch digestion in the small intestine is not well understood. Huntington et al. (1981) and Huntington (1984) measured glucose uptake from the intestines by determining blood concentrations in peripheral and portal veins. Net transfer of glucose was from the blood to the gut on diets which consistently showed a disappearance of starch between the duodenum and ileum. In another study, Huntington and Reynolds (1985) using cows fitted with catheters placed in arteries and veins, recovered only about 65% of the glucose and 35% of the infused starch in portal blood. To explain why starch disappearance from the SI does not match the amount of glucose appearing in the portal blood, tissue utilization has been proposed as a large sink. Also, microbial competition for glucose in the SI was suggested (Ben-Ghedalia, 1982; Nicoletti et al., 1985).

3.Large intestine

Starch fermentation in the large intestine results in production and absorption of VFAs, although fermentation at this site is of little energetic importance (Hungate et al.,1959). A large flow of indigested nutrients to the post ruminal digestive tract is thought to occur in high producing dairy cows during early lactation due to high concentrate intake, thus increasing fecal starch content and that available for fermentation in the large intestine (Plegge, 1986).

Starch fermentation in the cecum leads to synthesis of microbial protein from residual N in the digesta and urea N which enters the large intestine from the blood. Because this microbial N is excreted in the feces, with a correspondent fall in the urinary N excretion, there is a reduction in the apparent digestibility of dietary N (Orskov, 1986). Hence, starch fermentation in the large intestine and cecum is undesirable.

Some studies (Wheeler and Noller, 1976; Wheeler and Noller, 1977) showed a strong negative relationship between fecal starch content and fecal Ph. Other studies (Erdman et al., 1980; Killmer et al., 1979), however, have shown only a slight relationship.

Processed grain for cattle.

An extensive review of the effects of grain processing on starch availability was reported by Theurer (1986). Steam-flaking was best for improving starch availability of sorghum grain. In vitro and in situ data suggest that much of the increase of in starch fermentation with steam-flaking is due to changes in the starch granules which produce additive effects beyond those obtained from decreasing particle size (Theurer, 1986).

Moist-heat processing of barley or sorghum grain markedly increased in vitro VFA production by ruminal microorganisms (Theurer and al.,1967; Trei et al., 1970). Moreover, a close relationship between starch digestion and in vitro VFA production was noted (Trei et al., 1970).

Early experiments comparing dry rolling and steam flaking of sorghum grain for ruminal and total tract digestion with beef cattle (Kartchner, 1972; Hinman and Johnson, 1974; Garcia et al., 1981) showed an average of 28% more starch digested in the rumen and 5% more in the total tract with SFS. These differences resulted in higher feed efficiencies and superior gain. Thus, dry-rolled grains are no longer used for commercial feedlots (Hale and Prouty, 1980).

Although SFS has been used in feedlot diets, little has been incorporated to diets for lactating dairy cows. Generally, dairy producers have felt that performance of cows on high sorghum diets is inferior to that of cows fed corn or barley. Also, excessive ruminal degradability of starch results in acidosis, decreased ruminal fiber digestion (Hoover, 1986) and lower milk fat content. Studies have compared cereal grains with different starch digestibilities (using different varieties or the same varieties under different processing methods), but only few directly compared steam-flaking to dry-rolling diets for high producing dairy cows.

Bush et al. (1972) evaluated methods of processing grain for lactating dairy cows. Diets contained 50% concentrate and 50% alfalfa hay with 75% of the concentrate as sorghum grain. Trial 1 compared grain of coarse, medium or fine grind. Dry matter intakes and milk fat % were not affected by type of grinding. Milk yield was higher for the fine (21.4 kg/d) than coarse (20.6 kg/d) grinding and was intermediate for the medium grind (20.6 kg/d). In trial 2, grain was finely ground, finely ground and steamed, or finely ground, steamed and dry heated. Production was not altered by processing method. In trial 3, grain was finely ground; coarsely ground, cooked and pelleted (partially gelatinized); or finely ground, cooked and pelleted (completely gelatinized). Intake and milk fat were not affected by treatment, but milk yield was higher for the finely ground (23.8 kg/d) than for either diet with gelatinized grain (23.1 kg/d).

In a second report Bush et al. (1973) compared sorghum grain ground to three particle sizes (trial 1), and finely ground, steam-rolled or micronized sorghum grain (trial 2) in diets for lactating cows. Diets contained 50% concentrate of which sorghum grain comprised 70% with alfalfa hay as forage. In trial 1, DMI and milk fat percentage were not affected by treatment, but medium or fine grinding resulted in higher milk production (19.7 kg/d) than coarse ground (19.2 kg/d). In trial 2, DMI (16.9 kg/d) and milk production (26.9 kg/d) were not influenced by processing but fat percent averaged 2.8, 3.0 and 2.6% for grinding, steam-rolling and micronizing, respectively.

DePeters and Taylor (1985) compared corn and barley in complete cubed diets for lactating dairy cows. Diets contained 50% alfalfa hay and either 32% corn or 40% barley (34% NDF and 17% CP). Milk production, milk fat, DMI and digestibility of OM were not affected by grain type, but digestibility of fiber components was lower on barley diets.

Herrera-Saldana and Huber (1989) studied interactions between degradability of starch and protein for Holstein cows during early lactation. Diets contained either barley or sorghum grain and either cottonseed meal or brewers grains in a 2 x 2 factorial arrangement of treatments. Milk yield (35.3 kg/d) and DMI (24.3 kg/d) were not affected by grain source but milk fat percent was lower for barley than sorghum grain diets (3.0 vs. 3.5%), resulting in .1 kg/d less fat yield for barley diets. Starch digestibility was higher for barley (90%) than sorghum diets (81%).

Poore (1990) compared SFS and DRS in diets using either alfalfa hay or chopped wheat straw forage and found that steam flaking resulted in greater ruminal degradation of starch compared to dry rolled grain. Milk yields (31.5 vs. 28.1 kg/d) 3.5% FCM (29.8 vs. 28.2 kg/d), and feed efficiencies (1.49 vs. 1.38) were higher (P<.10) for SFS diets and intake of dry matter and starch were similar.

Theurer et al. (1991) compared steam flaked and dry rolled sorghum grain at two levels (35% and 43%) in diets using alfalfa hay as forage for lactating cows. Compared to dry rolled, the steam flaked grain improved milk (38.0 vs. 33.2 kg/d), milk protein yields and feed efficiencies at both concentrations, probably due to a improved digestibility of starch.

Utilization of highly degradable starch sources in ruminant diets was first adopted in finishing steer diets and lead to high concentrations of ruminal VFA, acidosis and reductions of intake. In order to overcome these problems, experiments were conducted comparing the effect of combining high and low degradable starch sources. Most of these trials were with beef cattle. Objectives were to decrease acidosis by replacing part of the highly degradable starch source with less degradable sources.

Stock et al. (1987a) fed different combinations of high moisture corn (HMC; high degradable starch source) and dry whole corn (DWC; low degradable starch source) to 62 finishing steers as 80% of diet DM for 132 days. Steers fed HMC alone consumed less feed than those fed DWC or mixtures of HMC and DWC. Steers fed the 50:50 combination gained faster and more efficiently than those fed 75:25 or 25:75 combinations. In a second experiment with 132 steers, a mixture of grains resulted in faster and more efficient gains than HMC or DWC alone. In a third trial 160 yearling steers received the treatment diets for after 108 days. Higher efficiencies of gain were shown for steers fed only HMC. The authors concluded that mixtures of HMC and DWC promote a faster and more efficient gains only during the 3-4 initial weeks of the stepping-up period from low to high concentrate diets.

Stock et al. (1987b) compared HMC and dry rolled sorghum grain as 80% of diet DM in steers from 291 to 383 kg. Combinations of grains tended to produce faster and more efficient gain than either 100% HMC or DRS. Reduction in incidence of acidosis was observed when part of HMC was replaced by DRS. Also, when 67% of the HMC was replaced by DRS, more DRS was digested in the rumen and more starch was digested in the small intestine than for the 100% HMC diet. The authors suggested that when starch digested more in the small intestine compared to the rumen, overall efficiency is improved. However, if all the starch in diets comes from DRS, capacity of the small intestine may be insufficient for digestion. Thus, the animals would consume more feed to maintain similar gain, which would reduce in feed efficiency.

Limited capacity of VFA absorption from the rumen might lead to a wastage of energy when animals are fed an excess of highly degradable starch (Orskov, 1986). This, and the hypothesis that digesting starch in the small intestine results in a more efficient utilization of nutrients than when digested in the rumen (Owens et al., 1986) suggest a benefit from combining grains with different starch degradabilities. Although some grain combination experiments have been conducted with beef cattle (Stock et al., 1987a, 1987b), reports of the use of this technique with high producing dairy cows are limited.

Brown et al. (1970) compared 45% concentrate diets containing either 54.4% sorghum grain and 17.4% barley or 54.4% barley and 17.4% sorghum grain in lactating dairy cows. Grain mixture were either steam-rolled or pelleted. Milk yields and milk fat percent were not influenced by treatment and averaged 25 kg/d and 3.0% respectively. DMI were not reported.

Summary.

Benefits of steam flaking sorghum grain on starch utilization and performance of beef cattle have been documented. The use of steam flaked sorghum in commercial feedlots in the Southwest is a common practice. However, it has not been incorporated into dairy diets. One of the objectives of this work is to compare steam flaked and dry rolled sorghum grain to corn a common, starch source used in the U.S..

Since feeding an excess of highly degradable starch may lead to digestive tract upsets in cattle and since products of starch digested in the SI are utilized more efficiently than those of rumen digestion, another objective of this study was to determine, through digestibility and metabolism studies, if lactating cows consuming large amounts of feed would take advantage of the starch which by-passes the rumen. Feeding of dry rolled sorghum is more likely to result in delivery of starch to the SI than steam flaked, so, an additional objective was to determine effects of feeding steam flaked and dry rolled sorghum in a 1:1 ratio to take advantage of both the greater rumen fermentation and higher efficiency resulting from more post ruminal starch delivery.

CHAPTER 3

EFFECT OF SORGHUM GRAIN PROCESSING ON THE PERFORMANCE OF LACTATING DAIRY COWS

ABSTRACT

Thirty six lactating Holstein cows (80 days in milk) were divided in four groups to compare steam rolled corn (CORN), steam flaked sorghum (SFS), dry rolled sorghum (DRS) and an equal mixture of SFS and DRS (MIX). Each grain comprised 42.2% of a total mixed ration (33 forage:67 concentrate). Treatment was for 80 d and included a 10 d digestibility trial using Cr_2O_3 as marker. Data from a 14 d pretrial period were used to allot cows to treatment and to adjust treatment means by covariance. DMI was higher for MIX ($P<.05$) than SFS. There were no significant differences ($P<.05$) in milk yields, FCM yields or milk fat percent, but SFS increased ($P<.05$) milk protein yield and %, milk lactose % and SNF % compared to DRS. Moreover, the SFS diet was superior ($P<.05$) to CORN and MIX in percent of lactose and SNF. Digestibility of organic matter was higher for SFS compared to CORN and DRS ($P<.05$), while that of CP and NDF was highest ($P<.05$) for DRS. Starch digestion was lowest ($P<.01$) for DRS (69.8%) and highest (92.3%) for SFS. Steam flaked sorghum grain was superior in milk

protein yields and content compared to dry rolled for lactating cows but variable effects were obtained from feeding a 1:1 mixture of DRS and SFS.

INTRODUCTION

Readily available energy in the form of starch for dairy cows represents a large percentage of a dairy herd's feed cost, especially for high producing cows during early lactation. Most of this starch comes from grains such as barley, corn, sorghum, wheat or oats.

Corn is one of the most common sources of starch for ruminants. However, when used for ruminants,less is available for human use and exportation. A non-competitive, energetic grain is sorghum. Sorghum presents high grain yields of high starch content and is generally less expensive than corn. Moreover, because sorghum grows better in dry areas, it is very important to the animal industry in the dry, arid regions of the world.

When not processed, sorghum starch is less degradable in the rumen than corn starch; but, if properly processed, degradability increases significantly, achieving utilization rates that are superior to that of corn. Steam flaking of sorghum grain has been highly effective in improving starch utilization and performance in beef cattle (Theurer, 1986); Hence, the practice is common in commercial feedlots in the Southwest U.S..

Although steam flaked sorghum has been used in feedlot diets, it has not been incorporated to a large degree in diets for lactating dairy cows. The reason for this is that dairy producers feel that performance of cows fed sorghum diets is inferior to that of cows fed corn or barley diets. Another reason is the concern that increasing ruminal degradability of starch would cause acidosis, thus decreasing ruminal fiber digestion (Hoover, 1986) and milk fat percent. Thus, there have been few studies comparing processed cereal grains in diets for high producing dairy cows.

Because an excess of highly degradable starch in the rumen may lead to a wastage of energy through gases loss (Orskov, 1986) and because starch digestion in the small intestine may be energetically more efficient (Owens et al. 1986), the combination of a high and a low degradable starch source in the diet might be beneficial to lactating cow.

The objective of this experiment was to compare performance of lactating cows fed steam flaked sorghum grain with that of cows fed dry rolled sorghum, corn or a mixture of steam flaked and dry rolled sorghum.

MATERIAL AND METHODS

Animals and diets.

Thirty-six Holstein cows (30 multiparous, 6 primiparous; 80 d in milk) were fed four diets containing steam-rolled corn (CORN), dry-rolled sorghum (DRS), steam-flaked sorghum (SFS) or a mixture of dry-rolled sorghum and steam-flaked sorghum (MIX) during an 80 d trial period. Cow were fed a common diet during a 14 d covariate period and were blocked on production and days in milk (DIM) and randomly assigned from within blocks to one of the four experimental diets. The experiment was conducted from December 1989 to March 1990 at the Dairy Research Center of the University of Arizona. Cows were housed in shaded pens equipped with Calan gates for measuring individual feed intakes.

Cows were fed ad libitum (10% refusal), with feed offered once daily, and had free access to water. Milk yields during the pretrial and treatment periods was recorded at 12 hour intervals. Milk from each cow was sampled weekly during two consecutive milkings and composites were analyzed for fat, protein, lactose, SNF and somatic cells counts using infrared analysis (Arizona DHIA). Cows were weighed following the morning milking for two consecutive days at the beginning and end of treatment.

Diets were formulated to contain 16.5% CP and to meet or exceed nutrient requirements of the cows (NRC, 1989) for energy, vitamins and minerals. Sorghum grain was either dry-rolled through a roller mill with rolls adjusted to coarsely grind the grain (472 g/l or 51 lb/bu) or steamed 1 hour and then flaked (360 g/l or 28 lb/bu). Steam-rolled corn was purchased from a local supplier. Corn was processed by passing briefly through a steam chamber and then through a roller mill. Ingredient composition of total mixed diets is in table 1. Diets were mixed weekly using a truck equipped with load cells and a mixing auger. Flakes of alfalfa hay (3 kg) were placed in the mixing truck and allowed to mix until stems have an average of about 10 cm. Other ingredients were then added and mixed until completely dispersed and hay stems reduced to 5 to 7 centimeters in length. Feeds offered and refused were collected at weekly intervals for each treatment and composited for the entire experiment.

Cows were weighted after morning milking, in two consecutive days at the beginning and the end of the experiment. The average of consecutive weighing was considered to be the body weight.

Digestibility trial.

During the last 14 d of the treatment period, a digestibility trial was conducted. Cows received diets mixed with Cr_2O_3 (.1% of diet DM) during 14 d. Feces were collected as grab samples (400 g) at 12 h intervals for the last 6 d and immediately frozen at -10^{0}C. During fecal collection, feeds were sampled daily and orts were totally collected and composited for each cow.

Blood and ruminal fluid collection.

On the last day of the experiment, blood and ruminal fluid samples were collected from the 4 cows with highest intakes on each treatment. Ruminal samples were obtained 4 h after the AM milking by a stomach tube using a vacuum pump, strained through 3 layers of cheesecloth, placed immediately on ice and frozen until analyzed for VFA concentrations. Rumen pH was measured immediately after straining, using an ionanalyzer (Orion Research Incorporated, Cambridge, MA). Blood samples (2 of 5 ml each) were collected from coccygeal vein. One sample was preserved with potassium oxalate and sodium fluoride for glucose analysis and the other was held without preservatives at room temperature for 2 h for analysis of urea.

Sample analysis.

Subsamples of feed and orts were dried at 100^{0}C for 24 h to determine DM. The remainder was dried at 55^{0}C and ground in a Wiley mill (2 mm screen) in preparation for analyses of other components.

Fecal samples were thawed and a 1 cm layer was spread in 16 x 26 cm aluminum foil tray and refrozen prior to freeze drying. Fecal samples were then ground through a Wiley mill (2 mm screen) and composited by animal on an equal DM basis. For starch analysis, all fecal composites and a subsample of each feed sample were reground to pass a 1 mm screen in a cyclone mill (UDY Corporation, Fort Collins, CO).

Feeds and fecal samples were analyzed for DM and organic matter (OM) according to AOAC (1980), for CP using an N autoanalyzer (Technicon, Terrytown, NY), for starch by the method of Poore et al. (1989), for NDF according to Robertson and Van Soest (1977) using alpha-amylase (type XI-B from bacillus sp, code A3051, Sigma Chemical Co., St. Louis. MO) as described by Poore et al., (1990) and for ADF by the Goering and Van Soest (1970) method. For Cr analysis, samples (.5 g) were prepared as for CP analysis, after which .4 g of periodic acid and 10 ml H_2O were added. The solution was boiled an additional 3 h to insure complete oxidation of Cr. Concentrations of Cr were determined using an atomic absorption spectrophotometer (Hitachi, Tokio, Japan). Ruminal VFA were measured using gas-liquid chromatography (Erwin et al.,1961) with tri-methyl acetic acid as the internal standard.

Rumen fluid samples were thawed and centrifuged for 15 minutes at 3000 g. Supernatant was stored at -4.0^{0}C until analyzed for VFA (5 ml acidified with 2 ml of 25% mataphosphoric acid) by gas chromatography with a 80/120 carbopack B-DA carbowax 20M column.

Blood samples were centrifuged at 1800 g for 20 minutes. Plasma from preserved blood was used to measure glucose in a YSI analyzer (model 27 glucose analyzer, YSI Inc., Yellow Spring, OH) and serum from non-preserved samples was analyzed for urea nitrogen according the method proposed by Cantarow and Trumper, 1975.

Statistical analysis.

Pretrial data for production parameters were used as covariates for those parameters. Data were analyzed by analysis of variance with the General Linear Model procedure of SAS (1985) using the following statistical model:

$$Y_{ijk} = \mu + A_i + COV_j + E_{ijk}, \text{ where}$$

μ = treatment mean,

A_i = effect of starch source,

COV_j = covariate,

E_{ijk} = random error.

Digestibilities, rumen VFA concentrations, pH, blood urea nitrogen, blood glucose and body weights were compared in a completely randomized design.

RESULTS

Although formulated to contain 16.5%, CP content in the diets ranged from 16.4% (MIX) to 18.3% (CORN). Concentrations of NDF (35.7-40.9%) and ADF (26.9-28%) were above the minimal recommendations from NRC (1989) for cows at this level of production (table 2). Covariate means for production parameters are in table 3. Intake of DM (kg/d) was not different between CORN, DRS and SFS, but was higher ($P<.01$) for MIX than SFS.

Cows fed SFS tended to produce more milk than those fed DRS, with CORN and MIX intermediate (table 3). Milk protein percent of cows fed SFS was higher ($P<.05$) than for those fed DRS. Lactose and SNF percentage were the highest ($P<.05$) when SFS was fed. No significant difference was observed between diets for milk fat percentage but there was a tendency for DRS to be highest and MIX lowest.

Gross efficiency of milk production was not different between treatments and averaged 1.17 kg milk/kg DMI. There was, however, a significant difference ($P<.05$) when considering FCM/kg DMI. Cows fed SFS were more efficient than those fed MIX. Efficiencies from cows on CORN and DRS were similar and did not differ ($P<.05$) from SFS or MIX.

No statistical difference was observed for BW change, and the average for all treatments was +13.7 kg/d. Although a wide range was observed among treatment means (-4.7 to 25.1 kg), no differences ($P>.05$) were detected due to large variation.

Digestibilities of all nutrients were affected by type of grain (table 4). CORN, DRS and MIX diets were similar in digestibilities of DM and ADF but SFS diets were higher for DM ($P<.10$) and lower for ADF ($P<.05$). Digestibility of OM was higher ($P<.01$) for SFS compared to CORN and DRS diets, but not higher than the MIX diet. Digestibility of NDF was higher ($P<.01$) for the DRS than SFS diet, with CORN and MIX intermediate. Digestibility of CP was highest ($P<.05$) for the for DRS (58.6%) diet and other treatments were similar (52.5%).

Starch digestibility was most affected by treatment with the SFS diet higher ($P<.01$) than CORN and MIX which were higher ($P<.01$) than DRS.

Blood urea nitrogen (BUN) and blood glucose (table 5) were not affected by treatment and averaged 13.2 and 46.5 mg/dl respectively. There was, however, a tendency for cows fed SFS and MIX diets to have lowest BUN, and cows on CORN have highest blood glucose.

There was a tendency for higher total rumen VFA for the MIX (93.4 mM) than DRS (68.8 mM) diet; whereas rumen pH was lower for MIX (6.5) than SFS (6.9). The MIX diet also was higher ($P<.05$) molar proportion of propionate (29.6 molar %) and lower in C2:C3 ratio (1.89) than DRS (21.6 molar % and 2.84). Values for molar proportions of acetate, butyrate, i-butyrate, valerate, i-valerate and 2-methylbutyrate did not differ between treatments and averaged 56.8, 12.6, 1.2, 1.7, 0.8 and 0.6, respectively.

DISCUSSION

There were no differences in DMI between DRS or SFS diets in studies by Poore (1990) and Theurer et al. (1991); neither in beef cattle fed SFS, dry rolled corn or steam flaked corn (Horton et al., 1982). Stock et al. (1987b) compared different levels of high moisture corn (a highly degradable starch source) and DRS in beef cattle and observed a linear increase ($P<.01$) in DMI as DRS in the diet increased. The reason for the high DMI found for MIX in the present experiment is unclear, but differences were not significant when DMI was expressed as a percent of BW.

Poore (1990) found that steam flaking of sorghum grain increased milk and milk protein yields and decreased milk fat percentage compared to DRS, although yield of milk fat was not affected. Theurer et al. (1991)

also found a significant increase of both milk and milk protein yields (P<.01) for cows fed SFS compared to DRS diets. These increases may be related to differences in energy available to the animals.

The higher the digestible energy intake (Herbein et al., 1978) or starch degraded in the rumen (Reynolds et al., 1988a), the more propionate production, absorption and conversion to glucose. Because propionate is the main substrate for gluconeogenesis in the liver, more glucose is available to the mammary gland when highly degradable starch is used in the diet. As lactose is the most important osmotic regulator controlling milk volume, an increase in the supply of its precursor, glucose, may result in an increase in milk production. In dairy cows, Lomax and Baird (1983) reported increased metabolizable energy intake, net portal blood flow and net output of nutrients with higher rumen fermentable starch in the diet. Higher starch degradability in the rumen can also increase flow of bacterial CP from rumen (Herrera-Saldana, 1987; McCarthy et al., 1989; Poore , 1990).

Significant increases were reported in conversion of feed to FCM (Poore, 1990; Poore et al.,1990; Theurer et al., 1991) for SFS compared to DRS. The present experiment confirmed higher gross efficiency of FCM probably due to superior extraction of energy from the SFS diet.

A major effect of feeding high concentrate diets to dairy cows is a decrease in ruminal pH due to greater production of VFA (Staples and Lough, 1989). Rumsey et al. (1970) showed the molar percent of ruminal propionate shifted from 16.4 to 38.9 when the diet was changed from all forage to all concentrate. Although all treatment diets were of high concentrate percentage, digestibility of the starch and rate of starch digestion were not the same (Poore et al., 1989; Herrera-Saldana, 1987). This may explain the tendency for the higher pH, the higher propionate concentration, and higher C2:C3 ratio on the MIX compared to the DRS diet (table 5). Although the SFS diet had a higher percent degradable starch than the MIX diet, the higher starch content of the MIX diet (table 2) along with a higher DMI (table 3) may explain the higher propionate concentration. Poore (1990) found no significant differences in total rumen VFA concentrations between cows fed SFS and DRS (72.5 mM). In the present experiment these treatments averaged 73.6 mM.

Despite the high concentrate level in all diets, rumen pH did not drop below 6.0, suggested by Owens and Goetsh (1988) to be detrimental to cellulolytic bacteria. Dietary factors responsible for this might have been inclusion of buffers and alfalfa hay in all diets. While added buffers neutralize acids from rumen fermentation (Chalupa and Schneider, 1985), alfalfa hay has a high buffering potential due to its high cation exchange capacity (Van Soest, 1987). Often, no response is observed when buffers are included in diets using alfalfa hay as the main forage (Staples and Lough, 1989). However, as suggested by Erdman et al. (1982), data regarding to pH from ruminal fluid obtained by stomach tube must be interpreted with caution due to salivary contamination.

Negative effects on milk fat appear when rumen molar proportion of propionate is more than 25% (Davis, 1979; Van Soest 1982); however Staples and Lough (1989), suggested a fat depression at molar proportions lower than 25% propionate. Although significant differences between treatments for molar proportion of propionate and C2:C3 ratios were detected, milk fat percent was not significantly altered and averaged 3.58%. However, DRS tended to present a higher milk fat percentage than the MIX diet. The lack of depressed milk fat despite shifts in rumen C2:C3 and propionate might be due to the added buffer which contained MgO and $NaHCO_3$. The $NaHCO_3$ directly affects rumen pH. Also, diets which depress milk fat result in decreased activity of lipoprotein lipase (LPL) in the mammary gland and increased activity in adipose tissue (Emery, 1976). Supplemental MgO tends to restore LPL to normal levels (Askew et al., 1971; Benson et al., 1972; Emery, 1973).

Another explanation for the lack of decrease in milk fat percentage may be that the FNDF:RDS ratio which it did not drop below .9. Poore (1990) suggested that the critical FNDF:RDS is between .9 and 1.0. In the present study this ratio ranged from .91 (SFS) to 1.36 (DRS) (table 2).

Changes in ruminal fiber digestion are often due to changes in rumen pH (Cheng et al., 1955; Emmanuel et al., 1970; Terry et al.,1970). Although no apparent differences in pH were observed, changes in digestibility did occur, reflecting a possible change in the microbial population. The higher values for ADF and NDF digestion in cows fed DRS may be due to a more active population of cellulolytic microorganisms.

Apparent digestibility of starch for DRS and SFS followed the same pattern found by Poore (1990) with dairy cows, with SFS (92.3%) higher ($P<.01$) than DRS (69.8%). Starch digestibilities in beef cattle are generally higher (Theurer, 1986), for DRS, probably due to a slower passage rate and lower intakes.

Van Soest (1982) suggested that feeding a highly degradable starch source combined with high intakes may increase the starch reaching the large intestine, which fermentation would draw endogenous N to the lumen of the lower digestive tract and decrease apparent digestibility of CP. Another hypothesis to explain the lower CP digestibility on SFS is that heat generated during sorghum processing would heat damage the protein and decrease the CP digestibility. Poore (1990), however found no differences for apparent digestibility of CP of SFS and DRS diets.

The lack of significant differences in blood glucose may be due to site of sampling. At the coccygeal vein, the glucose absorbed from the gut has already been utilized by the portal-drained viscera, metabolized by the liver or extracted by the mammary gland (Reynolds et al., 1988b; Huntington and Eiseman, 1988; Ferrel, 1988). Hence, effect of treatment on glucose concentrations might not be detected in coccygeal blood.

The tendency for lower blood urea N on the SFS than DRS and CORN diets may be due to less gluconeogenesis from protein on SFS. It has been reported that more urea N is recycled into the rumen when highly degradable starch sources are fed compared to sources of lower degradability (Prigge et al., 1978).

CONCLUSION

To date, limited information has been published regarding effects of feeding processed sorghum grain to lactating dairy cows. Unpublished studies in our laboratory have shown increases in milk, FCM, milk protein percent and efficiency of feed utilization. Similar trends were found in this experiment, although not significant for milk yields or efficiency. However milk protein yields and % were higher for SFS than DRS or CORN, as were % lactose and % SNF. With the anticipated changes in milk pricing systems, based on milk protein content, these effects have important economic implications.

Table 1. Ingredient composition of the experimental diets.

Ingredient, % of DM	Diet CORN	DRS	SFS	MIX
Steam rolled corn[1]	42.2	--	--	--
Dry rolled sorghum[2]	--	42.2	--	21.1
Steam flaked sorghum[3]	--	--	42.2	21.1
Alfalfa hay (18% CP)	28.0	28.0	28.0	28.0
Cottonseed meal (46% CP)	10.3	10.3	10.3	10.3
Whole cottonseed	8.0	8.0	8.0	8.0
Cottonseed hulls	4.0	4.0	4.0	4.0
Dried molasses	3.1	3.1	3.1	3.1
Mineral and vitamins[4]	2.0	2.0	2.0	2.0
Buffer[5]	1.9	1.9	1.9	1.9
Urea	0.5	0.5	0.5	0.5

[1]Starch availability 3.0 ml; gelatinization 23.7%; degradation rate 9.0 ml/h (as determined by Peterson Laboratories, Hutchinson, KS).
[2]Starch availability 16.4 ml; gelatinization 13.8%; degradation rate 5.6 ml/h (as determined by Peterson Laboratories, Hutchinson, KS).
[3]Starch availability 59.1 ml; gelatinization 55.7%; degradation rate 19.7 ml/h (as determined by Peterson Laboratories, Hutchinson, KS).
[4]$CaCO_3$ .66; Biophos .78; trace mineral salt .35; vit.A and D .21. Trace mineral salt composition: K(≥13%), S(≥12%), Zn(≥9%), I(≥.25%), Mn(≥5%), Fe(≥7.5%), Cu(≥1%), Co(≥.03%), Se(≥.013%).
[5]$NaHCO_3$ 1.27; MgO .63.

Table 2. Nutrient composition of experimental diets.

Nutrient, % of DM	Diet			
	CORN	DRS	SFS	MIX
Dry matter	93.2	93.2	92.5	93.2
Organic matter	93.3	93.4	93.2	90.3
Crude protein	18.3	18.2	17.5	16.4
Acid detergent fiber (ADF)	25.0	28.0	26.9	26.9
Neutral det. fiber (NDF)	37.5	42.3	38.2	40.9
Starch	27.5	27.6	30.8	30.4
RDS[1]	19.2	15.7	23.4	20.5
FNDF[2]	21.4	21.4	21.4	21.4
FNDF:RDS	1.11	1.36	0.91	1.04

[1]Percent of ruminally degradable starch (calculated from Theurer, 1986)
[2]Percent of forage NDF (ingredients ≥ 28% NDF were used for FNDF calculations; calculated from NRC, 1989).

Table 3. Intake and production by cows fed experimental diets[1].

Item	Diet				
	CORN	DRS	SFS	MIX	SEM[2]
DM intake					
kg/d	26.3ab[3]	26.1ab	24.8b	29.4a	1.26
% of BW	4.00	4.13	3.93	4.49	0.24
Yield, kg/d					
milk	30.2	29.4	31.0	30.9	0.92
3.5% FCM	31.1	30.6	30.8	29.7	1.19
milk fat	1.09	1.10	1.09	1.01	0.05
milk protein	0.89ab	0.86b	0.97a	0.95ab	0.03
Milk composition, %					
fat	3.61	3.73	3.64	3.33	0.15
protein	3.01ab	2.95b	3.10a	3.06ab	0.05
lactose	4.88b	4.84b	4.96a	4.84b	0.04
SNF[4]	8.55b	8.45b	8.72a	8.54b	0.07
SCC[5] (1000/ml)	66.0	71.0	58.0	120.0	37.0
Gross efficiency				1.10	
milk[6]	1.18	1.16	1.25	1.08b	0.07
FCM[7]	1.23ab	1.21ab	1.32a		0.06
				22.6	
BW change, kg	25.1	-4.7	11.8		9.99

[1]Covariate adjusted values.
[2]Standard error of the means.
[3]Values in a same row followed by different letters differ (P<.05).
[4]Solids not fat.
[5]Somatic cells count.
[6]Kg milk/kg DMI.
[7]Kg FCM/kg DMI.

Table 4. Apparent percent digestibility of nutrients in cows fed experimental diets.

Item	Diet				SEM[1]
	CORN	DRS	SFS	MIX	
Dry matter[2]	53.2b	52.4b	57.1a	54.5ab	1.41
Organic matter[3]	55.5b	54.3b	60.1a	56.9ab	1.36
Crude protein[4]	53.1b	58.6a	52.0b	51.8b	1.73
ADF[4]	35.1a	36.5a	27.5b	33.9a	2.35
NDF[3]	40.4ab	47.4a	35.3b	41.0ab	2.42
Starch[3]	82.3b	69.8c	92.3a	82.5b	3.17

[1]Standard error of the pooled mean.
[2]Values in a same row followed by different letters differ ($P<.10$).
[3]Values in a same row followed by different letters differ ($P<.01$).
[4]Values in a same row followed by different letters differ ($P<.05$).

Table 5. Blood urea nitrogen, blood glucose, ruminal volatile fatty acids and rumen pH in cows fed experimental diets[1].

	Diet				
Item	CORN	DRS	SFS	MIX	SEM[2]
Blood urea N, mg/dl	14.4	14.2	11.4	12.8	1.14
Blood glucose, mg/dl	50.0	44.2	46.8	45.0	2.24
Rumen pH	6.9	6.8	6.9	6.5	0.14
Ruminal VFA					
Total VFA, mMolar	77.2	68.8	78.4	93.4	7.69
VFA, mole/100 mole					
Acetate	56.0	60.6	56.4	54.2	2.02
Propionate	26.0ab[3]	21.6b	27.3ab	29.6a	2.21
Butyrate	13.2	12.9	12.1	12.4	0.57
i-butyrate	1.4	1.3	1.1	0.9	0.16
Valerate	1.6	1.8	1.8	1.8	0.08
i-valerate	1.0	0.9	0.7	0.6	0.13
2-methylbutyrate	0.8	0.7	0.6	0.5	0.12
C2:C3[4]	2.19ab	2.84a	2.10ab	1.89b	0.26

[1]Values from samples collected 4 hours post-feeding.
[2]Standard error of the pooled mean.
[3]Values in a same row followed by different letter differ (P<.05).
[4]C2=acetate; C3=propionate.

CHAPTER 4

EFFECT OF SORGHUM GRAIN PROCESSING ON SITE AND EXTENT OF DIGESTION OF STARCH IN LACTATING DAIRY COWS

ABSTRACT

Four lactating Holstein cows, fitted with a t-type cannula in the proximal duodenum were used in a 4 x 4 Latin square design to study the effects of sorghum grain processing on site of digestion of nutrients. Steam flaked sorghum (SFS), dry rolled sorghum (DRS), steam rolled corn (CORN) and an equal mixture of SFS and DRS (MIX) were fed as 42.9% (DM basis) of a TMR (35:65 forage to concentrate ratio). Intake, duodenal and fecal starch averaged 6.8, 2.1 and 0.7 kg/d. However, total tract digestibility of starch was higher ($P<.05$) for SFS than for DRS and MIX diets and starch from SFS tended to have higher rumen disappearance than starch from other diets. There was also a tendency for higher efficiency of conversion of dietary CP to bacterial protein and of higher BCP flow to the duodenum for the SFS diet. Cows fed SFS had higher ($P<.01$) fecal pH, and tended to have lower fecal CP and higher total apparent digestion of CP than those fed other diets. Energy digestibility data suggest an effect of processing on digestion of nutrients other than starch.

INTRODUCTION

Steam flaking of sorghum grain is known to improve starch degradability (Hale,1973; Theurer, 1986). Highly degradable starch sources have also been reported to increase microbial protein flow to the duodenum of beef (Prigge et al,1978) and dairy cattle (McCarthy et al,1989; Herrera-Saldana, 1987; Poore; 1990). However, little data is available comparing processed and unprocessed sorghum to corn, a common starch source used in dairy rations.

If the starch component of the diet is made-up partially of a highly degradable starch source (in order to guarantee enough energy for better ruminal digestion of nutrients) and partially of a lower degradable starch source (to allow more starch to bypass the rumen and be digested in the small intestine) it might result in greater benefits to the animal.

The objective of this experiment was to evaluate the effect of sorghum grain processing on the extent and site of digestion of starch and other nutrients, as well as microbial protein production. Comparison of sorghum to corn was also deemed important.

MATERIAL AND METHODS

Animal and diets.

Four Holstein cows in mid lactation (average 124 d in milk) fitted with single t-type intestinal cannulae were used. All cannulae had a gutter-type flange similar to those described by Wanderley et al. (1985). The experiment was conducted at the Dairy Research Center of the

University of Arizona from May to July of 1990. Cows were housed in individuals pens (4 x 8 m) with dirt floor and shade.

Cow were fed ad libitum (10% refusal) once daily between 10 and 11:30 am, and had free access to water. The four experimental diets were formulated to contain 16.5% CP and to meet or exceed nutrient requirements of the cows (NRC, 1989) for energy and minerals. Treatments consisted of steam-rolled corn purchased from a local supplier, sorghum grain, either dry-rolled through rolls adjusted to coarsely grind the grain (472 g/l or 51 lb/bu) or steamed 1 hour and then flaked (360 g/l or 28 lb/bu), and an equal mixture of the processed sorghum grain. These treatments will be herein referred to as CORN, DRS, SFS and MIX, respectively. Ingredient composition of diets is given in table 4. There were slight alterations from lactation trial diets in order to adjust for differences in nutrient content of certain ingredients. Diets were mixed weekly using a truck equipped with load cells and a mixing auger. Flakes of baled alfalfa hay (3 kg) were placed in the mixing truck and allowed to mix until stems had an average length of about 10 cm. Other ingredients were then added and mixed until completely dispersed and hay stems were reduced to 5 to 7 cm in length. Water was sprayed on the DRS diet to equalize DM of all diets.

Chromium oxide was the digestibility marker used to estimate nutrient flow to the small intestine, as well as ruminal and total tract digestibilities. Each cow received orally, gelatin capsules containing 12 g of Cr_2O_3 at 12 hour intervals during the entire experiment.

Experimental design.

A 4 x 4 Latin square design with 21 day periods was used. The first 17 days of each period was for adaptation to diets and the last 4 days for collection of feed, fecal and duodenal samples. Data were analyzed using the General Linear Model procedure of SAS (1985) program using the following statistical model:

$$Y_{ijkl} = \mu + A_i + B_j + C_k + E_{ijkl}, \text{ where}$$

μ = treatment mean,

A_i = treatment effect,

B_j = animal effect,

C_k = period effect,

E_{ijkl} = random error.

Sample collection.

Individual samples of feed offered and refused were collected the last 4 days of each period. Feces and duodenal digesta were sampled every 6 hours. Sampling time was delayed by 2 h each day, so that samples represented every 2 h of a 24 h period.

After digesta present in cannulae was discarded, 500 ml of duodenal digesta was collected. Samples were homogenized and divided in two portions; 250 ml were immediately frozen in a 16 x 26 cm aluminum foil tray for freeze drying and future analysis and 250 ml were stored in a plastic container and kept at 2^0C, following the procedures of Hsu and Fahey (1990) for future bacterial CP determination. The same container was used to store the 12 samples from the same cow in a period and weighted samples were composited for each cow.

Grab samples of feces (400 g) were measured for pH with an ionanalyser (Orion Research Incorporated, Cambridge, MA) and frozen immediately at -20C. After thawing, feces were spread in a 16 x 26 cm aluminum foil tray and refrozen in preparation for freeze drying. After freeze drying, fecal and duodenal samples were ground in a Wiley mill (2 mm screen) and composited by animal and period on an equal DM basis.

Composite fecal, duodenal and feed samples were reground to pass a 1 mm screen in a cyclone mill (UDY Corporation, Fort Collins, CO) prior to starch analysis.

Blood samples (2 of 5 ml each) were collected from coccygeal vein every 15th day of each period at 2 h intervals, from 6 AM to 6 PM. One sample from each time was preserved with potassium oxalate and sodium fluoride for glucose analysis and the other was held without preservatives at room temperature for 2 h for analysis of urea.

Cows were weighted after morning milking, every 16th day of each period.

Nutrient analysis.

Subsamples of feed and orts were dried at 100^{0}C for 24 h for calculations of DMI. The remaining subsample was dried at 55^{0}C and ground in a Wiley mill (2 mm screen) in preparation for subsequent analysis. Fecal samples were thawed and a 1 cm layer was spread in a 16 x 26 cm aluminum foil tray and refrozen for freeze drying. After freeze drying, fecal and duodenal samples were ground through a Wiley mill (2 mm screen) and composited on an equal DM basis.

Feed, duodenal and fecal samples were analyzed for DM and OM according to AOAC (1980). Determination of CP was with an autoanalyzer (Technicon, Terrytown, NY), and that of starch used a glucose oxidase following enzymatic hydrolysis (Poore et al., 1990). The method of Robertson and Van Soest (1977), as described by Poore et al. (1990a), was used to determine NDF, and ADF was by the method of Goering and Van Soest (1970). Chromium in fecal and duodenal samples were prepared as in experiment 1 and analyzed using atomic absorption spectrophotometry with an air-acetylene flame (Hitachi, Tokyo, Japan). Samples for starch analysis were gelatinized by autoclaving, hydrolysed with amyloglucosidase (Diazyme L-200, Miles, Inc., Elkhart, IN), and glucose released was then determined with immobilized glucose oxidase-peroxidase (Model 27 glucose analyzer, Yellow Springs Instruments, Inc. Yellow Spring, OH) as described by Poore et al. (1989a). Gross energy content of feed, duodenal and fecal samples was determined using an automatic adiabatic bomb calorimeter (model 1241, Parr Instrument Co., Moline, IL) and a calorimeter controller (model 1710, Parr Instrument Co., Moline, IL). Ammonia content of duodenal digesta was determined by the method used by Poore (1990). Samples (2 g) were mixed with 50 ml of water and left for 1 h at room temperature. Total N in the solution was determined using the N autoanalyzer. Purine content of duodenal digesta was determined by the method of Zinn and Owens (1986).

Blood samples were centrifuged at 1800 g for 20 minutes. Plasma from preservad blood was used to measure glucose (by the glucose-oxidase method) in a YSI analyzer (model 27 glucose analyzer, YSI Inc., Yellow

Spring, OH), and serum from non-preserved samples was nalyzed for urea nitrogen according the method proposed by Cantarow and Trumper, 1975.

Bacteria present in duodenal samples were isolated by differential centrifugation according to Zinn and Owens (1986) as modified by Hsu and Fahey (1990): Refrigerated duodenal samples were mixed with a saline solution (NaCl .9%) in a ratio of 2:1, were blended for 2 min in a Waring blender (T.K. Heller Corp., Floral Park, NY) to separate bacteria from feed particles and were filtrated through 3 layers of cheesecloth to remove large feed particles. Filtrate was centrifuged at 150 x g for 10 minutes to remove small feed particles. Supernatant was then transferred to high speed centrifuge tubes and samples were spun at 14,600 x g for 15 min. Supernatant was discarded and isolated bacteria were removed and dried in a ventilated oven at 50^{0}C for 24 h. Samples of isolated bacteria were analyzed for purine, following the procedure of Zinn and Owens (1986), and for DM, OM and CP following the same procedures as for feed and feces analysis.

Bacterial DM contribution to duodenal DM was determined as follow:

$$DM\ reaching\ duodenum\ x\ \frac{\%\ of\ purine \in duodenal\ digesta}{\%\ of\ purine \in bacteria}\ ,$$

and OM truly fermented in the rúmen was determined as follow:

$$OM\ intake\ -\ (\ duodenal\ OM\ -\ microbial\ OM\ )\ .$$

RESULTS

Nutrient composition of experimental diets is in table 7. The CP content was above the expected and ranged from 18.2% (SFS) to 19.6% (DRS). However, all diets contained sufficient nutrients to meet the cows requirements (NRC, 1989).

Most of the parameters studied were not significantly ($P<.05$) affected by treatment. One reason was the high variation occurring within animals fed different diets. As shown in table 8, two animals were in early lactation and two in mid lactation at the beginning of the trial. Because feed intake and other production parameters relate to stage of lactation, part of the variation found may have been due to the different stages of lactation rather than diet. Moreover, passage rate, one of the main factors influencing extent of digestion, is affected by feed intake and differed among cows.

Results of production parameters are in table 9. There were no significant difference ($P>.05$) for daily milk, FCM, milk fat or milk protein yield or gross efficiency of feed conversion to milk or FCM. Averages were, 27.8, 26.3, .88, .78 1.23 and 1.16, respectively. Milk fat percent was not affected by treatment . The average was 3.19, but milk from cows fed CORN tended to contain less fat than other treatments. Milk protein percent of cows fed CORN or MIX were higher ($P<.05$) than for those fed DRS.

Except for the fecal flow and the apparent digestion of starch no other metabolic parameter showed a statistically significant difference between diets.

Intake, duodenal flow and fecal flow of DM averaged 22.37, 13.98 and 8.64 kg/d, respectively (table 10). Duodenal passage of DM from feed and bacteria averaged 10.13 and 3.85 kg/d, respectively. There was, however, a tendency for cows fed SFS to produce more bacterial DM than those fed CORN. Flow of feed DM at the duodenum tended to be higher for DRS than other diets. Apparent and microbial corrected ruminal and total tract digestibilities of DM averaged 37.4, 54.8 and 60.8 respectively. The SFS diet had a tendency for higher digestion in the total tract.

Ruminal organic matter (OM) digestibilities (table 11) followed a pattern similar to DM digestibilities. Average rumen fermented organic matter (RFOM) for all diets was 12.7 kg/d and the CORN diet tended to ferment more OM in the rumen than the DRS.

Intake, duodenal and fecal starch averaged 6.81, 2.06 and 0.68 kg/d respectively (table 12). Fecal starch of cows on the SFS diet was lower ($P<.01$) than those fed other diets. Ruminal and post-ruminal starch digestibility averaged 69.3 and 68.5%, respectively. Total tract digestibility of starch differed ($P<.05$) between treatments. Cows fed SFS had the highest (97.16%) and those fed DRS the lowest values (84.58%), with other treatments intermediate.

Blood urea nitrogen and blood glucose did not differ ($P<.05$) between treatments and averaged 16.2 and 51.5 mg/dl, respectively (table 13). Fecal pH of cows fed SFS was higher ($P<.01$) than that of cows on other treatments (Table 16).

Results for energy are in table 14. Intake, duodenal and fecal energy averaged 99.8, 63.0 and 38.8 Mcal/d, respectively. The percentage of energy apparently digested in the rumen averaged 36.5 Mcal/d, while that digested post-ruminally and in the total tract amounted 37.2 and 60.5%, respectively, of the ingested.

Extent of digestion of ADF and NDF followed similar patterns (table 16). Average rumen and total tract digestibilities were 36.3 and 34.4% for ADF, and 40.0 and 40.0% for NDF respectively. Cows fed the DRS diet tended to have more ADF and NDF digested in the total tract than those fed other diets.

Intake, duodenal flow and fecal flow of CP (table 17) averaged 4.20, 3.28 and 1.40 kg/d, respectively. Of the total CP reaching the duodenum, 3.09 kg/d was non-ammonia CP (NACP). The NACP fraction, which contains the bacterial and feed CP, tended to be higher for SFS diets due to a higher amount of bacterial CP. The NACP reaching the duodenum averaged 26% less than CP intake with smallest decreases on the SFS diet and greatest for DRS. Bacterial CP averaged 53.5% of the NACP reaching the duodenum. The SFS diet tended to yield the highest BCP/RFOM and greatest conversion of dietary CP digested in the rumen (DCPDR) to BCP reaching the duodenum. Average amount of CP in feces was 1.4 kg/d with cows fed SFS tending to be the lowest. Apparent and corrected ruminal digestibility of CP, as well as total tract digestibility, averaged 20.3, 60.9 and 65.6%, respectively.

DISCUSSION

As expected, digestion of starch in the total tract was greater ($P<.05$) for SFS than DRS (Theurer, 1986). Although not significant the same tendency was observed for total tract digestibility of DM and OM. Moreover, there was a tendency for higher ruminal digestion of starch for cows fed SFS than DRS. Ruminal starch degradability in diets for lactating cows have been altered by others. McCarthy et al. (1989) substituted barley for corn and reported that ruminal and total tract starch digestibilities were higher for steam-rolled barley than for ground corn. Herrera-Saldana et al. (1987) compared barley and DRS, showing that ruminal and total tract starch digestibilities were higher for barley (80 and 94%) than for DRS (50 and 88%); whereas, Poore (1990) compared SFS and DRS and found higher values for SFS (74 and 98%) than for DRS (48 and 83%). In the present study ruminal and total tract starch digestibilities were 81.3 and 97.2% for SFS and 59.7 and 84.6% for DRS, while values found for CORN and MIX were intermediate. These data show that increasing starch degradability of cereal grains not only increases starch disappearance in the total tract but also changes site of starch digestion. Total tract digestion was 14.9% higher for SFS compared to DRS. The major change, however, was in the rumen where starch of SFS was 36% more digestible. These data agree with those of Poore (1990), in which the starch source with higher rumen degradability (SFS) also had highest post-ruminal digestion. Despite increasing percent digestibility of starch in the SI, steam flaking decreased supply of starch to that site. These observations agree with those of Owens et al. (1986).

It has been suggested that starch digested in the SI is utilized more efficiently than that digested in the rumen (Owens et al. 1986). Theurer (1986), however, related higher efficiency of weight gain in beef cattle with greater ruminal digestion of starch. Carpenter (quoted by Van Soest, 1982) stated a limit of 1 kg/d for starch digested in the SI. Herrera-Saldana et al. (1990) reported an intake of starch of 5.4 kg/d, rumen escape of 2.8 kg/d and disappearance in the SI of 1.1 kg/d. Our results, in which 1.71 kg/d disappeared post-ruminally suggest that the limit for SI starch digestion is above that stated by Carpenter. Amounts of starch digested in the small and large intestine were not determined.

Fecal pH is largely influenced by VFA content in feces which depends on amount of fermentable substrate degraded in the cecum as well as the amount of VFA absorbed at that site (Ulyatt et al., 1975; Wheeler et al., 1977). Wheeler et al. (1977) found a significant negative correlation between fecal pH and fecal starch. The higher fecal pH of SFS ($P<.01$) compared to other treatments reflects smaller concentration of VFA in feces, and suggests a less fermentable substrate reaching the cecum. Moreover, less fermentative activity in the cecum decreases endogenous N mobilization and provides greater N retention and higher apparent digestibility of CP.

Although no significant difference ($P<.05$) across treatments for digestibility of energy at the different sites of the digestive tract was observed, grain processing apparently influenced digested energy fractions. Table 15 shows that 69% of the digested energy in the SFS diet came from starch, while starch contributed 47 to 52% of digested energy in other diets. Only 15% of the energy digested post-ruminally came from starch on the SFS diet compared to 26 to 28% in other diets. Because digestibility of energy entering the intestines tended to be highest for the SFS diet (44.3%), and because post-ruminal starch in this diet was less than in other diets, grain processing apparently affects post-ruminal digestion of energy from nutrients other than starch. Energy losses and end products of starch degraded in the rumen and digested in the small intestine are different, resulting in different energy values. It is recognized that the figure used to estimate the energy value of starch disappearing in the rumen and post-rumen is not precise for those estimations because only the value for glucose is used (4.18 kcal/g). However, this was employed because of the lack of a better value. Moreover, this comparison was only to demonstrate the large difference between diets in site of energy utilization resulting from the dietary starch sources.

A decreased ruminal pH caused by increased ruminal starch availability may result in depressed digestion of fiber (Hoover, 1986). In the current study ruminal digestibility of ADF and NDF did not change when different grains were fed. There was, however, a tendency for cows fed CORN to produce a lower percent of milk fat than those fed other diets. It was suggested that fiber digestion, C2:C3 ratio and milk fat percentage decrease when the ratio of forage NDF to ruminally degradable starch (FNDF:RDS) is low. Poore et al., (1989b) suggested that the critical limit for FNDF:RDS is between .9 and 1.0. The ratio found in this study ranged from 0.91 (SFS) to 1.20 (DRS) (table 12). This may be one reason why fat percentage did not decrease with these high concentrate diets.

Values for ADF and NDF digestibilities in the total tract were similar to values found for the production trial. All ADF values for total tract digestibility were slightly lower than ruminal digestibility. For NDF this fact occurred only for CORN diet. These observations agree with the data of Poore (1990).

Duodenal flow of NACP tended to be highest for SFS, lowest for DRS, with CORN and MIX diets intermediate. However, total NACP reaching the duodenum was less than the total CP intake. Many authors have reported the NACP flow to the duodenum higher than the CP intake when lactating cows (Herrera-Saldana, 1987; McCarthy et al., 1989; Poore, 1990) or steers (Wanderley et al. 1987) received high concentrate diets. These authors reported that NACP flow to the duodenum was 19 to 36% more than the dietary CP intake in lactating cows and 40% higher in steers. However, other researchers have found a decrease in duodenal NACP compared to CP intake (Zinn and Owens, 1983; Prigge et al., 1978) ranging from 6 to 24%, similar to the decrease found in this study of 13% (SFS) to 38% (DRS). Possible explanations are high degradable protein in the diets or inefficient capture of ammonia for microbial protein synthesis.

Bacterial CP (BCP) flow tended to be higher for SFS than other diets. Previous studies have indicated that the flow of BCP increases with higher degradable starch intake in lactating cows (McCarthy et al, 1989; Herrera-Saldana, 1987; Poore, 1990). This was associated with higher OM truly digested in the rumen (RFOM). In the present experiment, however, treatments did not significantly affect (P>.05) the amount of RFOM.

Values for BCP to dietary CP digested in the rumen ratio (BCP:DCPDR) were highest for the SFS diet although not significantly (P>.05), compared to DRS, MIX and CORN.

Microbial efficiency as well as bacterial DM and BCP production did not differ (P>.05) across treatments. If nutrients other than energy were not limiting growth of bacteria, and mass of bacteria produced per unit of ATP was constant (Bauchop and Elsden, 1960), we would expect bacterial yield to be a linear function of energy availability or ruminally digested OM. Hence, microbial protein production per unit OM digested in rumen should remain constant. Recent studies show that growth of rumen bacteria is stimulated when ruminal starch degradability is increased (Sniffen and Robinson, 1987; Herrera-Saldana, 1987; McCarthy et al., 1989; Poore,1990). In these studies, however, ruminal starch digestibility of the low degradable starch sources (DRS or grounded shelled corn) ranged from 42.6 to 49.5%, and that from high degradable sources from 71.1 to 80.0%. In the current experiment ruminal starch digestibilities did not significantly differ across treatments, but tended to be lower for DRS (59.7%) than SFS (84.5%). Values for DRS were higher than those found by other authors (Herrera-Saldana, 1987; McCarthy et al., 1989; Poore,1990) for the low-degradable starch sources. Our results suggest that available energy in the rumen did not limit bacterial growth even in the DRS treatment of low degradability.

The tendency of lower CP excretion for the SFS diet may be a result of less endogenous N due to the lower amount of starch available for fermentation in the large intestine and cecum. The higher fecal pH on SFS supports this view.

CONCLUSION

Steam flaking of sorghum decreased the amount of fecal starch and increased total tract digestion of starch compared to normal processing by dry rolling. Steam flaking also tended to increase flow of BCP to SI, along with improving efficiency of conversion the dietary CP digested in the rumen (DCPDR) to bacterial protein. In addition to increasing ruminal degradation of starch, steam flaking also improved post-ruminal starch digestion. However, the increase in percent of starch disappearing in the post-ruminal digestive tract may have been due to the smaller quantity entering the small intestine which did not challenge the amylolytic potential as would diets which deliver greater quantities of starch to the post-ruminal tract.

Table 6. Ingredient compositon of the experimental diets.

Ingredient, % of DM	Diet			
	CORN	DRS	SFS	MIX
Steam rolled corn[1]	42.9	--	--	--
Dry rolled sorghum[2]	--	42.9	--	21.5
Steam flaked sorghum[3]	--	--	42.9	21.4
Alfalfa hay (18% CP)[4]	23.0	23.0	23.0	23.0
Cottonseed meal (46% CP)	7.3	7.3	7.3	7.3
Whole cottonseed	9.0	9.0	9.0	9.0
Cottonseed hulls	10.0	10.0	10.0	10.0
Dried molasses	3.2	3.2	3.2	3.2
Mineral and vitiamins[5]	2.0	2.0	2.0	2.0
Buffer[6]	1.9	1.9	1.9	1.9
Urea	0.7	0.7	0.7	0.7

[1]Analysis: DM, 85.9%; CP, 9.3%.
[2]Analysis: DM, 87.2%; CP, 10.5%.
[3]Analysis: DM, 85.9%; CP, 10.1%.
[4]Analysis: DM, 86.6%; CP, 22.0%; ADF, 28.0%; NDF, 33.1%.
[5]$CaCO_3$ .66; Biophos .78; trace mineral salt .35; vit.A and D .21.
Trace mineral salt composition: K(≥13%), S(≥12%), Zn(≥9%), I(≥,25%), Mn(≥5%), Fe(≥7.5%), Cu(≥1%), Co(≥.03%), Se(≥.013%).

Table 7. Nutrient composition of experimental diets.

	Diet			
Nutrient, % of DM	CORN	DRS	SFS	MIX
Dry matter	91.0	89.3	90.1	90.5
Organic matter	92.2	92.1	92.7	92.6
Crude protein	18.5	19.6	18.2	19.1
Gross energy (Mcal/kg)	4.43	4.46	4.35	4.41
Acid detergent fiber (ADF)	22.7	21.4	21.7	21.0
Neutral det. fiber (NDF)	33.9	31.6	32.5	31.8
Starch	29.6	31.6	30.6	31.7

Table 8. Distribution of cows within experimental diets and periods, and respective DMI and milk production averages.

	COW			
Period	300 (124)[1]	302 (137)	1158 (85)	932 (82)
I	CORN (20.3)[2] (21.4)[3]	DRS (21.3) (30.3)	SFS (21.1) (36.4)	MIX (23.7) (31.1)
II	DRS (20.2) (19.4)	SFS (21.2) (18.7)	MIX (26.1) (38.2)	CORN (30.0) (41.0)
III	SFS (20.7) (18.7)	MIX (18.9) (20.4)	CORN (24.0) (33.9)	DRS (29.4) (41.0)
IV	MIX (17.2) (18.7)	CORN (17.0) (22.0)	DRS (20.3) (24.7)	SFS (26.3) (29.8)

[1]Days in milk at the beginning of the experiment.
[2]Dry matter intake (kg/d).
[3]Milk production (kg/d).

Table 9. Intake and production by cows fed experimental diets.

Item	Diet CORN	DRS	SFS	MIX	SEM[1]
DM intake					
kg/d	22.81	22.83	22.35	21.48	1.94
% of BW	3.73	3.73	3.66	3.55	0.33
Yield, kg/d					
milk	29.6	28.8	25.9	27.2	4.18
3.5% FCM	26.7	27.5	24.3	26.5	3.67
milk fat	0.86	0.93	0.81	0.91	0.12
milk protein	0.85	0.77	0.72	0.78	0.11
Milk composition, %					
fat	2.92	3.27	3.21	3.35	0.20
protein	2.91a[2]	2.67b	2.82ab	2.91a	0.09
Gross efficiency					
milk[3]	1.28	1.24	1.16	1.24	0.12
FCM[4]	1.16	1.19	1.08	1.21	0.09

[1]Standard error of pooled treatment mean.
[2]Values in a same row followed by different letters differ (P<.05).
[3]Kg milk/kg DMI.
[4]Kg FCM/kg DMI.

Table 10. Intake, and ruminal and total tract digestibility of dry matter (DM) in cows fed experimental diets.

Item	Diet				SEM[1]
	CORN	DRS	SFS	MIX	
DM intake, kg/d	22.81	22.83	22.35	21.48	1.94
DM flow, kg/d					
Duodenal DM	14.10	14.78	13.97	13.06	1.71
Bacterial	3.81	3.61	4.16	3.83	0.73
Feed	10.29	11.17	9.82	9.23	1.35
Fecal DM	9.08	8.92	7.99	8.56	0.93
Digestibility, %					
Ruminal					
Apparent	36.75	36.41	37.78	38.77	5.28
Corrected[2]	54.63	51.51	56.30	56.86	4.57
Total tract	58.69	60.08	64.79	59.54	4.39

[1]Standard error of pooled mean.
[2]Corrected for bacterial DM.

Table 11. Intake, and ruminal and total tract digestibility of organic matter (OM) in cows fed experimental diets.

Item	Diet				SEM[1]
	CORN	DRS	SFS	MIX	
OM intake, kg/d	21.22	21.10	20.85	20.07	1.78
OM flow, kg/d					
Duodenal OM	11.58	12.54	11.89	11.04	1.44
Bacterial	3.60	3.41	3.98	3.65	0.70
Feed	7.98	9.13	7.91	7.39	1.15
RFOM[2]	13.24	11.97	12.94	12.68	1.36
Fecal OM	8.20	8.03	7.32	7.78	0.86
Digestibility, %					
Ruminal					
Apparent	44.36	41.63	43.14	44.62	4.84
Corrected[3]	62.51	57.04	62.13	63.13	4.43
Total tract	60.01	61.21	65.44	60.71	4.24

[1]Standard error of pooled treatment mean.
[2]RFOM = OM freely fermented in the rumen.
[3]Corrected for bacterial OM.

Table 12. Intake, and ruminal and total tract digestibility of starch in cows fed experimental diets.

Item	Diet				SEM[1]
	CORN	DRS	SFS	MIX	
Starch intake, kg/d	7.04	6.89	6.62	6.68	0.87
Starch flow, kg/d					
Duodenal	2.10	2.72	1.24	2.16	0.50
Fecal	0.70a[2]	1.01a	0.20b	0.80a	0.23
FNDF[3]	4.9	4.2	5.4	4.5	--
FNDF:RDS[4]	1.02	1.20	0.91	1.05	--
Digestibility, %					
Ruminal	70.41	59.74	81.28	65.64	8.03
Entering intestines[5]	68.29	62.26	82.72	60.53	7.92
Total tract	90.81ab	84.58b	97.16a	88.82b	3.19

[1]Standard error of pooled treatment mean.
[2]Values in a same row followed by different letters are different (P<.05).
[3]From table 16.
[4]Ratio of forage fiber to ruminally degradable starch.
[5]Digestibility of starch entering the duodenum.

Table 13. Blood urea nitrogen[1], blood glucose[1] and fecal pH of cows fed experimental diets.

Item	Diet				SEM[2]
	CORN	DRS	SFS	MIX	
Blood urea N, mg/dl	16.5	16.1	16.6	15.6	0.92
Blood glucose, mg/dl	51.7	50.3	52.1	52.0	1.71
Fecal pH	6.1b[3]	6.1b	6.3a	6.1b	0.09

[1]This data is an average from seven blood samples collected from 6 AM to 6 PM, at 2 h intervals.
[2]Standard error of polled treatment mean.
[3]Values in a same row followed by different letters differ ($P<.01$).

Table 14. Intake, and ruminal and total tract digestibility of gross energy (GE) in cows fed experimental diets.

Item	Diet				SEM[1]
	CORN	DRS	SFS	MIX	
GE intake,Mcal/d	102.5	102.8	97.5	96.4	9.05
GE flow, Mcal/d					
Duodenal energy	62.8	65.7	64.7	58.7	7.59
Fecal energy	40.8	39.5	36.4	38.4	4.13
Digestibility, %					
Ruminal	36.82	36.97	33.76	38.26	6.01
Entering intestines[2]	34.58	36.23	44.30	33.69	6.70
Total tract	58.60	60.44	63.20	59.65	4.41

[1]Standard error of pooled treatment mean.
[2]Digestibility of gross energy entering the duodenum.

Table 15. Percent energy from starch digestion compared to the total energy digested ruminally and post-ruminally.

Site	Diet CORN	DRS	SFS	MIX
Rumen				
Total, Mcal/d[1]	39.7	37.1	32.8	37.7
Starch, Mcal/d[2]	20.6	17.4	22.5	18.9
Participation, %[3]	51.8	46.9	68.6	50.1
Post-rumen				
Total, Mcal/d[1]	22.0	26.2	28.3	20.3
Starch, Mcal/d[2]	5.8	7.1	4.3	5.7
Participation, %[3]	26.4	27.1	15.2	28.1

[1]Calculated from table 14.
[2]Calculated from table 12; starch energy = 4.18 kcal/g; this value does not express the real energetic value resulting from starch degradation in the rumen or in the small intestine due to different types of end products and extent of losses in both sites.
[3]Percentage of total energy coming from starch.

Table 16. Intake, and ruminal and total tract digestibility of neutral detergent fiber (NDF) and acid detergent fiber (ADF) in cows fed experimental diets.

Item	Diet				SEM[1]
	CORN	DRS	SFS	MIX	
Intake, kg/d					
NDF	7.98	7.34	7.80	7.23	0.62
ADF	5.40	5.34	5.30	4.93	0.43
FNDF[2]	4.9	4.2	5.4	4.5	--
Digestibility, %					
Ruminal					
NDF	36.32	43.57	39.35	40.61	6.69
ADF	34.26	40.20	36.79	34.07	8.04
Total tract					
NDF	35.03	44.18	41.86	39.05	8.28
ADF	32.50	38.08	34.46	32.69	8.86

[1]Standard error of pooled treatment mean.
[2]Percent of forage NDF (Ingredients ≥ 28% NDF were used for FNDF calculations; values used for alfalfa hay came from table 6; values for others ingredients came from NRC, 1989).

Table 17. Intake, and ruminal and total tract digestibility of crude protein (CP) in cows fed experimental diets.

Item	Diet				SEM[1]
	CORN	DRS	SFS	MIX	
CP intake, kg/d	4.19	4.63	3.97	4.02	0.47
Duodenal CP, kg/d	3.38	3.13	3.60	3.02	0.41
Ammonia CP	0.19	0.21	0.15	0.20	0.03
Non-ammonia CP	3.19	2.91	3.44	2.83	0.39
(Variation)[2]	(-19.46)	(-38.08)	(-13.21)	(-29.60)	(8.74)
Bacterial	1.54	1.64	1.92	1.58	0.34
(As % NACP)[3]	(49.10)	(53.46)	(55.29)	(56.30)	(6.42)
Feed	1.65	1.28	1.52	1.25	0.23
BCP/RFOM[4]	12.38	13.22	14.65	12.87	2.30
BCP/DCPDR[5]	0.54	0.48	0.77	0.59	0.29
Fecal	1.48	1.47	1.25	1.40	0.15
Digestibility, %					
Ruminal					
Apparent	14.43	33.29	9.47	24.19	8.52
Corrected[6]	55.24	66.56	58.31	63.64	5.42
Total tract	62.43	66.43	68.58	64.98	4.47

[1]Standard error of pooled treatment mean.
[2]Variation of non-ammonia CP (NACP) compared to CP intake.
[3]Percentage of NACP that comes from BCP.
[4]Grams of BCP/100 g truly ruminally fermented organic matter.
[5]BCP:Dietary CP digested in the rumen.
[6]Corrected for bacterial crude protein.

CHAPTER 5

SUMMARY

Two experiments were conducted to evaluate the influence of sorghum grain processing on digestion characteristics and lactational performance in lactating dairy cows. Treatments in both trials were fed as TMRs (36% forage : 64% concentrate). Percentage of grain on a DM basis was approximately 42.6% and the four starch sources compared were steam-rolled corn (CORN), dry-rolled sorghum (DRS), steam-flaked sorghum (SFS) and an equal mixture of SFS and DRS (MIX).

The first experiment was a lactation trial which included a digestibility phase. There was no difference in milk, FCM and milk fat production across treatments. However, cows on the MIX diet consumed more DM than those on SFS causing a lower gross efficiency for FCM production of MIX compared to SFS diet. Milk protein production as well as protein, lactose and SNF percentages in milk were higher for the SFS diet, while no difference was observed for milk fat percentage. Starch from SFS was better digested than starch from MIX and CORN or DRS (which was the lowest). Fiber components and CP were better digested on the DRS compared to the SFS diet. The higher gross efficiency for FCM found for the SFS diet may be the result of greater available energy from that diet.

The second experiment was conducted with four duodenally cannulated cows in a Latin square design. Starch from the SFS diet was degraded in

the total tract and tended to be more degraded in the rumen compared to other diets. The lowest amount of fecal starch found in cows fed SFS may be the cause of the higher fecal pH for those animals. Also, the tendency for higher digestibility of CP in that diet may be a result of less loss of endogenous N, and related to less fermentable substrate in the lower tract for stimulation of microbial growth at that site. Feeding SFS also tended to increase the efficiency of conversion of dietary CP digested in the rumen to bacterial protein, as well as flow of BCP to the small intestine.

The superior results found when feeding SFS to lactating dairy cows may be a combined effect of higher available energy for absorption and better utilization of dietary CP for synthesis of bacterial protein. In this study the utilization of SFS did not impair fiber utilization to the point that decreased milk fat percent was observed. Possible reasons may be: that the FNDF:RDS ratio greater than .9, that alfalfa hay was the main forage and that buffers ($NaHCO_3$ and MgO) were fed.

The mixture of SFS and DRS, although superior in some respect to DRS alone, was not better than SFS alone. The higher intake of the MIX diet in the production trial was not expected and might deserve future confirmation. Another important area for further investigation is the limit of starch digestion in the post-ruminal digestive tract.

CHAPTER 6

LITERATURE CITED

AOAC. 1980. Official methods of analysis. 14th ed. Assoc. Offic. Anal. Chem., Washington, DC.

Askew, E.W., J.D. Benson, J.W. Thomas and R.S. Emery. 1971. Metabolism of fatty acids by mammary glands of cows fed normal, restricted roughage or magnesium oxide supplemented rations. J. Dairy Sci. 54:854.

Bauchop, T. and S.R. Elsden. 1969. The growth of microorganisms in relation to their energy supply. J. Gen. Micro. 23:457.

Ben-Ghedalia, D. 1982. Fate of digesta ribonucleic acid in the small intestine of sheep. J. Dairy Sci. 64:2422.

Benson, J.D., E.W. Askew, R.S. Emery and J.W. Thomas. 1972. Metabolism of fatty acids by adipose tissue and liver of cows fed normal, restricted roughage or MgO supplemented rations J. Dairy Sci. 55:83.

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. 53:1488.

Bush, L.J., B.J. Steevens, K.E. Rauch and R.M. Alexander. 1972. Methods of processing sorghum grain for lactating dairy cows. Okla. Agr. Exp. Sta. MP-87:146.

Bush, L.J., R.M. Alexander, G.D. Adams and R.D. Morrison. 1973. Relation of method of processing sorghum grain to utilization by dairy cows. Okla. Agr. Exp. Sta. MP-90:227.

Cantarow, A and M. Trumper. 1975. Clinical Biochemistry. W.B. Saunders Co., Philadelphia, PA. pp.207-209.

Chalupa W. and P.L. Schneider. 1985. Buffer for dairy cattle. In: Proceedings of the Pacific NW Nutrition Conference, Boise, ID, pp.131-147.

Cheng, E., W.G. Hall and W. Burroughs. 1955. A method for the use of cellulose digestion by whashed suspensions of rumen microorganisms. J. Dairy Sci. 38:1225.

Clary, J.J., G.E. Mitchell, Jr., C.O. Little and N.W. Bradley. 1969. Pancreatic amylase activity from ruminants fed different rations. Can. J. Physiol. Pharmacol. 47:161.

Davis, C.L. 1979. The use of buffers in the rations of lactating dairy cows. In: W.H. Hale and P. Meinhardt (Ed.). Regulation of Acid-base Balance. pp 51-64. Church and Dwight Co. Inc., Piscataway, NJ.

Delfino, F.J. 1986. Identification and characterization of cereal grain tissues resistant to rumen microbial digestion using in situ, in vitro and scanning electron microscope techniques. Ph.D. Dissertation. University of Arizona, Tucson.

DePeters, E.J. and S.J. Taylor. 1985. Effects of feeding corn or barley on composition of milk and diet digestibility. J. Dairy Sci. 68:2027.

Emery, R.S. 1973. Biosynthesis of milk fat. J. Dairy Sci. 56:1187.

Emery, R.S. 1976. High energy feeds for milk production. In: M.S. Weinberg and A.L. Scheffner (Ed.). Buffers in Ruminant Physiology and Metabolism. pp 149-159. Church and Dwight Co. Inc., New York, NY.

Emmanuel, B., M.J. Lawlar and D. McAlesse. 1970. The effect of phosphate and carbonate-bicarbonate supplements on the rumen buffering system of sheep. Br. J. Nutr. 24:653.

Erdman, R.A., R.L. Botts, R.W. Henkem and L.S. Bull. 1980. Effect of dietary sodium bicarbonate and magnesium oxide on production and physiology of early lactation. J. Dairy Sci. 63:923.

Erdman, R.A., R.W. Hemken and L.S. Bull. 1982. Dietaty sodium bicarbonate and magnesium oxide for early postpartum lactating dairy cows: effects on production, acid-base metabolism, and digestion. J. Dairy Sci. 65:712.

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

Ferrel, C.L. 1988. Contribution of the visceral organs to animal energy expenditures. J. Anim. Sci. 66(Suppl. 3):23.

French, D. 1973. Chemical and physical properties of starch. J. Anim. Sci. 37:1048.

Garcia, J. A., C.B. Theurer and W.H. Hale. 1981. Digestao ruminal e pos-ruminal do amido, em novilhos alimentados com dois niveis de grao de sorgo floculado. Rev. Soc. Bras. Zoot. 10:235.

Goering, H.K. and P.J. Van Soest. 1970. Forage fiber analysis (apparatus, reagents, procedures, and some applications). Agric. Handbook 379.ARS-USDA, Washington, DC.

Hahn, D.H., J.M. Faubion, S.H. Ring, C.A. Doherty and L.W. Rooney. 1982. Semiautomated in vitro analysis of sorghum protein availability via pronase hydrolysis. Cereal Chem. 59:132.

Hale, W.H. 1973. Influence of processing on the utilization of grains (starch) by ruminants. J. Anim. Sci. 37:1075.

Hale, W.H. and F. Prouty. 1980. Grain processing system for milo and corn. University of Arizona Cattle Feeder's Day. pp 5.1-5.4.

Herbein, J.H., R.W. Van Maanen, A.D. McGilliard and J.W. Young. 1978. Rumen propionate and blood glucose kinetics in growing cattle fed isoenergetics diets. J. Nutr. 108:994.

Herrera-Saldana, R.E. 1987. The Effect of Synchronization of Protein and Starch Degradation in the Rumen on Nutrient Utilization and Milk Production in Dairy Cows. Ph.D. Dissertation. University of Arizona, Tucson.

Herrera-Saldana, R.E. and J.T. Huber. 1989. Influence of varying protein and starch degradabilities on performance of lactating cows. J. Dairy Sci. 72:1477.

Hinman, D.D. and R.R. Johnson. 1974. Influence of degree of micronization on the site and extent of sorghum starch digestion in beef cattle fed high concentrate rations. J. Anim. Sci. 39:958.

Hoover, W.H. 1986. Chemical factors involved in ruminal fiber digestion. J. Dairy Sci. 69:2755.

Horton, J.M., D.P. Hutcheson, C.R. Richardsn and W.L. Mies. 1982. The effects of grain processing and calcium source and level on finishing steers performance. In: Proceedings of American Society of Animal Science, Western Section, V.33. pp 49-52

Hsu, J.T. and G.C. Fahey, Jr. 1990. Effects of centrifugation speed and freezing on composition of ruminal bacterial samples collected from defaunated sheep. J. Dairy Sci.72:149.

Hungate, R.E., G.D. Phillips, A. McGregor, D.P. Hungate and H.K. Buechner. 1959. Microbial fermentation in certain mammals. Science 130:1192.

Huntington, G.B. 1984. Net absorption of glucose and nitrogenous compounds by lactating Holstein cows. J. Dairy Sci. 67:1919.

Huntington, G.B. and J.H. Eisemann. 1988. Regulation of the nutrient supply by gut and liver tissues. J. Anim. Sci. 66(Suppl. 3):35.

Huntington, G.B. and P.J. Reynolds. 1985. Net portal absorption of metabolites in beef heifers fed hay or concentrate and abomasally infused with glucose or starch. J. Anim. Sci. 61(Suppl. 1):467.

Huntington, G.B., R.L. Prior and R.A. Britton. 1981. Glucose and lactate absorption of metabolites and metabolic interrelationships in steers changed from low to high concentrate diets. J. Nutr. 111:1164.

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

Kartchner, R.J. 1972. Starch digestion in the bovine as influenced by level and processing of sorghum grain. M.S. Thesis, University of Arizona, Tucson.

Killmer, L.H., L.D. Muller and P.J. Wangness. 1979. Sodium bicarbonate addition to rations of pre- and postpartum cows. J. Dairy Sci. 63:2026.

Lomax, M.A. and G.D. Baird. 1983. Blood flow and nutrient exchange across the liver and gut of the dairy cow. Br. J. Nutr. 49:481.

Mayes, R.W. and E.R. Orskov. 1974. The utilization of gelled maize starch in the small intestine of sheep. Brit. J. Nutr. 32:143.

McCarthy, R.D., T.H. Klusmeyer, J.L. Vicini, J.H. Clark and D.R. Nelson. 1989. Effects of source of protein and carbohydrate on ruminal fermentation and passage of nutrients to the small intestine of lactating cows. J. Dairy Sci. 72:2002.

McNeill, J.W., G.D. Potter and J.K. Rigss. 1971. Ruminal and postruminal carbohydrate utilization in steer fed processed sorghum grain. J. Anim. Sci. 33:1371.

Moe, P.W. and H.F. Tyrrell. 1977. Effects of feed intake and physical form on energy value of corn in timothy hay diets for lactating dairy cows. J. Dairy Sci. 60:752.

Moe, P.W. and H.F. Tyrrell and N.W. Hooven, Jr. 1973. Physical form and energy value of corn grain. J. Dairy Sci. 56:1298.

Moore, J.A.; M.H. Poore; T.P. Eck; M.J. Arana; R.S. Swingle and J.T. Huber. 1990. Influence of sorghum grain processing and buffer inclusion on the performance and digestibility by lactating Holstein cows. J. Dairy Sci. 73(suppl 1):127 (abstr).

National Research Council. 1989. Nutrient requirements for dairy cattle. Natl. Acad. Sci., Washington, DC.

Nicoletti, J.M., C.L. Davis, R.B. Hespell and J.A.Z. Leedle. 1985. Enumeration and presumptive identification of bacteria from the small intestine of sheep. J. Dairy Sci. 67:1226.

Orskov, E.R. 1986. Starch digestion and utilization in ruminants. J. Anim. Sci. 63:1624.

Owens, F.N. and A.L. Goetsh. 1988. Ruminal Fermentation. In: D.C. Church (Ed.). Ruminant Animal - Digestive Physiology and Nutrition. pp 145-171.

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

Pfost, H.B. 1971. Effect of feed processing on digestibility of animal feeds. In: H.Swan and D. Lewis (Ed.). Nutrition Conference for Feed Manufacturers. University of Notttingham, Edimburg, page 50.

Plegge, A.W. 1986. Effect of two sources of calcium carbonate on milk yield, composition and nutrient use by lactating dairy cows. M.S. Thesis, University of Illinois, Urbana.

Poore, M.H. 1990. Effects of Sorghum Grain Processing and Forage Fiber Source on Milk production, Digestibility and Kinetics of Passage in Holstein Cows. Ph.D. Dissertation. University of Arizona, Tucson.

Poore, M.H., J.A. Moore and R.S. Swingle. 1990. Differential passage rates and digestion of neutral detergent fiber from grain and forages in 30, 60 and 90% concentrate diets fed to steers. J. Anim. Sci. 68:2965.

Poore, M.H., T.P. Eck, R.S. Swingle and C.B. Theurer. 1989. Total starch and relative starch availability of feed grains. Abstract of the 20th biennial conference on rumen function, November 7-9, 1989 (abstr.#35).

Prigge, E.C., M.L. Galyean, F.N. Owens, D.G. Wagner, and R.R. Johnson. 1978. Microbial protein synthesis in steer fed processed corn rations. J. Anim. Sci. 46:249.

Reynolds. C.K., G.B. Huntington, H.F. Tyreel and P.J. Reynolds. 1988a. Net metabolism of volatile fatty acids, D-β-hydroxybutyrate, nonesterified fatty acids, and blood gases by portal-drained viscera and liver of lactating Holsein cows. J. Dairy Sci. 71:2395.

Reynolds. C.K., G.B. Huntington, H.F. Tyreel and P.J. Reynolds. 1988b. Net portal-drained visceral and hepatic metabolism of glucose, L-lactate, and nitrogenous compounds in lactating Holstein cows. J. Dairy Sci. 71:1803.

Ridges, A.P. and A.G. Singleton. 1962. Some quantitative aspects of digestion in goats. J. Physiol.(London) 161:1.

Sniffen, C.J. 1980. The use of by-pass protein in ration formulation. In: Proc. 40th American Feed Manufact. Assoc. Nutr. Council, page 40.

Sniffen, C.J. and P.H. Robinson. 1987. Microbial growth and flow as influenced by dietary manipulations. J. Dairy Sci. 70:425.

Robertson, J.B. and P.J. Van soest. 1977. Dietary fiber estimation in concentrate feedstuffs. J.Anim. Sci. (Suppl. 1):254 (Abstr.).

Rooney, L.W., J.H. Faubion and C.F. Earp. 1983. Scanning electron microscopy of cereal grains. In: D.B. Betchel (Ed.). New Frontiers in Food Microstructure. pp 201-239. American Assoc. of Cereal Chem. St. Paul, MN.

Rooney, L.W., and R.L. Pflugfelder. 1986. Factors affecting starch digestibility with especial emphasis on sorghum and corn. J. Anim. Sci. 63:1607.

Rumsey, T.S., P.A. Putnam, J. Bond and R.R. Oltjen. 1970. Influence of level and type of diet on ruminal pH and VFA, respiratory rate and EKG patterns of steers. J. Anim. Sci 31:608.

Russel, J. R., A.W. Young and N.A. Jorgensen. 1981. Effect of dietary cornstarch intake on pancreatic amylase and intestinal maltase and pH in cattle. J. Anim. Sci. 52:1177.

SAS. 1985. SAS Users Guide: Statistics. SAS Inst., Inc., Carey, NC.

Staples, C.R. and D.S. Lough. 1989. Efficacy of supplemental dietary neutralizing agents for lactating dairy cows. A review. Anim. Feed Sci. Technol. 23:277.

Stock, R.A., D.R. Brink, R.A. Britton, F.K. Goedeken, M.H. Sindt, K.K. Krenkemeier, M.M.L. Bauer and K.K. Smith. 1987b. Feeding combinations of high moisture corn and dry rolled grain sorghum to finishing steers. J. Anim. Sci. 65:290.

Stock, R.A., D.R. Brinks, R.T. Brandt, J.K. Merrill and K.K. Smith. 1987a. Feeding combinations of high moisture corn and dry corn to finishing cattle. J. Anim. Sci. 65:282.

Terry, R.A., S.B. Connel and G.E. Outon. 1970. Some effects of feeding supplements of maize meal and sodium bicarbonate upon digestion of forage cellulose by sheep. Proc. Nutr. Soc. 29:12A.

Theurer, C.B. 1986. Grain processing effects on starch utilization by ruminants. J. Anim. Sci. 63:1649.

Theurer, C.B., J.S. Oliveira, Z. Wu, J.T. Huber, R.S.Swingle, M.H. Poore, R.C. Wanderley, M. Arana, J. Sullivan, M. Denigan and A. Al-Denah. 1991. Steam flaking with two dietary grain levels improves digestible starch intake and performance by lactating cows. J. Dairy Sci. 74 (Suppl 1):246.

Theurer, C.B., J. Trei and W.H. Hale. 1967. In vitro volatile fatty acids production as influenced by steaming processing and flaking of milo and barley. Proc. West. Sec. Amer. Soc. Anim. Sci. 18:189.

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

Ulyatt, M.J.; D.W. Dellow; C.S.W. Reid and T. Bauchop. 1975. Structure and function of the large intestine of ruminant. In: I.W. McDonald and A.C.I. Warner (Ed.). Digestion and Metabolism in the Ruminant. pp 119-133.

Van Hellen, R.W., T.A. Wilson, G.E. Mitchell, Jr., G.T. Schelling and R.E. Tucker. 1978. Bovine amylase, insulin and glucose response to high and low concentrate diets. J. Anim. Sci. 47(Suppl. 1):445.

Van Soest, P.J. 1982. Nutritional Ecology of the Ruminant. O & B Books Inc., Corvallis, OR.

Van Soest, P.J. 1987. Practical aspects of forage quality. In: Proceedings of Southwest Nutrition Management Conference, University of Arizona, page 90.

Waldo, D.R. 1973. Extent and partition of several grain starch digestion in ruminants. J. Anim. Sci. 37:1062.

Wanderley, R.C.; C.B. Theurer and M. Poore. 1987. Duodenal bacterial and non-bacterial protein supply in steers fed forage and grain diets. J. Anim. Sci. 64:295.

Wanderley, R.C., C.B. Theurer, S. Rhanema and T.H. Noon. 1985. Automated long-term total collection versus indicator methods to estimate duodenal digesta flow in cattle. J. Anim. Sci. 61:1550.

Wheeler, W.E. and C.H. Noller. 1977. Gastrointestinal tract pH and starch in feces of ruminants. J. Anim. Sci. 44:131.

Wheeler, W.E. and C.H. Noller. 1976. Limestone buffers in complete mixed rations for dairy cattle. J. Dairy Sci. 59:1789.

White, R.G., V.J. Willians and R.J.H. Morris. 1971. Acute in vitro studies on glucose absorption from the small intestine of lambs, sheeps and rats. Brit. J. Nutr. 25:57.

Zinn, R.G. and F.N. Owens. 1986. A rapid procedure for purine measurements and its use for estimating net ruminal protein synthesis. Can. J. Anim. Sci. 66:157.

Zinn, R.A. and F.N. Owens. 1983. Site of protein digestion in steers: predictability. J. Anim. Sci. 56:707.