EFFECT OF SORGHUM GRAIN PROCESSING AND FAT SUPPLEMENTATION ON PERFORMANCE AND NUTRIENT UTILIZATION IN LACTATING DAIRY COWS

by
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A Dissertation Submitted to the Faculty of the

DEPARTMENT OF ANIMAL SCIENCES

In Partial Fulfillment of the Requirements
For the Degree of

DOCTOR OF PHILOSOPHY

In the Graduate College

THE UNIVERSITY OF ARIZONA

1 9 9 5

UMI Number: 9603705

THE UNIVERSITY OF ARIZONA
GRADUATE COLLEGE

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entitled Effect of Sorghum Grain Processing and Fat Supplementation on Performance and Nutrient Utilization in Lactating Dairy Cows.

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SIGNED: José Manuel Simas

ACKNOWLEDGMENTS

I wish to thank all the people that helped me during my studies in the University of Arizona. Special thanks go to Dr. J.T. Huber, my major professor for his guidance and encouragement throughout my graduate studies. I wish to thank Drs. Theurer, Rice, Armstrong, and Reed. I also thank Dr. Wise and Price for filling in at the last minute.

Special thanks to Dr. Z. Wu and "Walter" Chen for their assistance in the development and completion of this study.

Thanks are also extended to other members of faculty and students, and staff for their help in the conduction of the experiments.

Finally I want to thank my family for their love, support, and encouragement throughout my life.

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ABSTRACT

Three experiments were conducted to determine effects of fat supplementation and ruminal starch degradability on lactation performance, and nutrient digestions in lactating cows.

Four cannulated cows were used in a 4X4 Latin square design to determine effects of fat supplementation and ruminal starch degradability on ruminal fermentation and nutrient flow to the duodenum. Treatments were:1) dry-rolled sorghum (DRS), no added fat; 2) DRS plus 2.5% fat; 3)steam-flaked sorghum (SFS), no added fat; 4) SFS plus 2.5% fat. SFS resulted in higher total VFA, propionate and butyrate, and the lowest C2:C3 ratios compared to DRS when fat was not added to the diets. Diets with SFS had higher ruminal (73.4 vs. 52.1%) and total tract (99.1 vs 95.0%) starch digestibilities then those with DRS. Duodenal flows of total CP and microbial protein were not affected by diets. Fat supplementation increased milk production, ruminal propionate and total VFA concentration and decreased C2:C3 ratio in diets containing DRS.

In another, study 40 cows alloted to five dietary treatments: 1) DRS, no added fat; 2) DRS plus 2.5% fat; 3) SFS no added fat; 4) SFS plus 2.5%; 5) SFS plus 5% fat. Milk yield was increased by SFS and fat supplementation (2.5% of DM), the

effects being additive. Fat supplementation at 5% did not improve lactation performance but increased body weight gain. Milk composition was not affected by treatments; however, milk protein yield was increased by SFS. Digestibilities of starch were increased (98.2 vs. 92.6%) with SFS compared to DRS.

In the third trial, 48 cows were used in a 2X3 factorial arrangement of treatments. Diets contained DRS or SFS with 2.5% of cottonseed oil, tallow, or prilled fatty acids. Compared to DRS, SFS did not affect milk production, but increased milk protein content, body weight gains and estimated NE_L (22.6%) of sorghum grain, regardless of fat source. Fat sources did not affect lactation response, however prilled fatty acids tended to decrease DMI. SFS increased DM, OM, CP, and starch digestibilities, regardless of fat source.

CHAPTER 1

INTRODUCTION

Most common feedstuffs for ruminants are low in fat, and fat supplementation to diets for lactating cows has increased milk yield (Palmquist, 1984). Recommended limits for feeding fat often are based on influence on ruminal metabolism and/or on utilization of fatty acids by the cow. Most sources of fat such as vegetable oils, animal fats and oil seeds inhibit rumen microbial activity, so their use to increase dietary fat concentration to 5-6% often results in a depression in rumen fermentation and/or fiber digestion. Ruminal inert fats have partially overcome this limitation and allowed for inclusion of larger amounts of fat in lactation diets; however, too high fat may compromise feed intake and production responses. Moreover high fat intakes, digestibility of nutrients are decreased. Commercially inert fats are more expensive than natural fats, thus, an economic strategy might be to maximize utilization of normal fats in dairy diets and add inert fats to a profitable level. Milk protein percentages decrease when cows are fed diets with added fat (Wu and Huber, 1994).

Studies at the University of Arizona consistently showed that increasing degradability of starch in sorghum by steam-flaking vs. dry-rolling of the grain increased percentages as well as yields of milk protein (Theurer, 1995). It was hypothesized that the availability of amino acids (AA) for milk protein synthesis may increase when more starch is degraded in the rumen, either by higher microbial protein synthesis in the rumen, and/or by increased ruminal propionate that may spare AA from gluconeogenesis in the rumen. Wu et al. (1994) demonstrated that increased propionate availability for gluconeogenesis did not result in increased milk protein percentages, but that ruminal infusion of glucose, which tended to increase microbial protein synthesis, did increase the percentage of milk protein.

In one study Simas et al.(1995) showed that increasing starch degradability by steam flaking counteracted the depressing effect of added fat on milk protein percentage, in very early post partum cows, but the added fat depressed DMI and did not affect lactation performance.

The objectives of this study were: 1) to determine effects of sorghum grain processing and fat supplementation on ruminal fermentation and nutrient passage to the duodenum of lactating cows. Such information might explain why steam-flaked sorghum overcomes milk protein depression associated with fat supplementation; 2) to determine whether steam-flaking of sorghum grain and added fat are additive in a milk and milk protein yield in cows at peak lactation; 3) to determine interactions between three fat sources (one ruminally inert, and two natural, but varying in saturation) and ruminal starch availability on lactation performance and nutrient digestibilities of high producing dairy cows.

CHAPTER 2

LITERATURE REVIEW

FAT UTILIZATION BY LACTATION DAIRY COWS

Lactating cows are often fed large amounts of high starch grains to increase ration energy density in an attempt to meet heavy energy demands for milk production. However, the amount of grain that can be fed is limited because cows require a minimum amount of fiber for rumination and maintenance of proper rumen function. A way to increase the energy density of the ration while maintaining adequate fiber, is supplementation of fat.

The high energy density of fat makes it an attractive feed additive for the high producing dairy cow that spends a considerable part of her lactation in a negative energy balance. Improved lactational performance, body condition, and reproduction are potential benefits that may be derived from minimizing the stress associated with a negative energy balance (Grummer, 1994).

In estimates with lactating cows, supplemental fat has yielded approximately 3 times more NE_L than carbohydrates or carbohydrate-rich feeds, which is in contrast with the 2.25 factor based on gross energy content of the different feeds (Davis, 1993). A reason for higher estimates for lactating cows are: 1) long chain fatty acids are not fermented in the rumen while carbohydrates undergo extensive fermentation, and this fermentation results in energy losses, and 2) efficiency of use of the energy in the end products of carbohydrate fermentation (primarily VFA) is less (56-62%) than that of long chain fatty acids resulting from fat digestion (77-82%) (Davis, 1993).

When fat supplementation has been used to increase energy density of diets for lactating cows, generally there has been a beneficial effect on milk production (Palmquist, 1984). Effects on rumen fermentation affect level and type of fat that should be fed. Excess fat inhibits microbial protein synthesis necessary for maximizing intakes, and fiber and N utilization. Feeding systems have been developed using supplemental fat in lactating cows diets to increase energy intake without negative effects on ruminal function (Palmquist, 1988).

SOURCES OF DIETARY FAT

Diets formulated from forages, grains and oil-seed meals average 3 to 4% fat. The grains contain 2 to 3%, oil seed meals are variable. The solvent process yields protein supplement with 2% fat; whereas the expeller meals contain 4 to 5% fat (Chalupa and Ferguson, 1990). Most forages contain

2 to 4% fat, which are in leaf chloroplast. Leaf lipids are mainly galactolipids, containing glycerol, galactose, and unsaturated fatty acids such as linoleic, linolenic, and oleic acids, and also sulfonate groups (Chalupa, 1991; Van Soest, 1994). Leaf lipids are lower in energy because of their higher polarity (Van Soest, 1994).

Whole cottonseed (WCS) and whole soybeans (WSB) are the most commonly used natural fat sources, because of their desirable nutrient profiles. WCS contains 23% protein, 34% ADF, and 20% fat, with 18% fat, 48% protein, and 10% ADF in WSB. Polyunsaturated fatty acid (PUFA) composition of the fat in WCS and WSB are 73%, and 85% respectively. Such a high content of PUFA is generally not inhibitory to rumen microbes when fed as part of a whole seed, because rate of oil release allows for hydrolysis and biohydrogenation to occur without affecting rumen function (Mohamed et al., 1988; Palmquist, 1984).

Animal fat sources such as tallow and lard contain relatively large amounts of saturated fatty acids, which have less of a negative effect on rumen fermentation. Animal fats and vegetable fats are comparable in their energy value, even though they differ in fatty acid composition and handling characteristics (Hutjens, 1990).

Protected fats are designed to that have little effect on rumen fermentation, with digestion occurring in the small intestine. Ruminal inertness is achieved by forming calcium salts of long chain fatty acids or by a high proportion of saturated long chain fatty acids such as palmitic or stearic acids (Chalupa et al., 1984, 1986; Palmquist, 1984; Palmquist and Jenkins, 1980). Sodium alginate encapsulation might also improve ruminal inertness of fats (Shaver, 1990; Smith, 1991). Hydrogenation of fats increases saturation of fatty acids and their melting point making them more inert in the rumen (Jenkins and Jenny, 1989).

Commercialized ruminally-inert fats include; Dairy Fat Prills®, B.P. Nutrition, U.K.; Energy Booster 100®, Milk Specialties Co., IL.; Megalac®, Volac Ltd., U.K., Church and Dwight., NJ,; Alifet USA, U.S.; Carolac®, CBP Resources, Inc., NC.; Dairy 80®, Morgan Mfg., U.S.; Booster Fat®, Balanced Energy Co., U.S.; Qual-Fat® Dairy Blend, National By-Products, Inc., IL.; Calcium-Tallowate®, Bucckeye Cellulose Co., TN. Fat content and saturated fatty acids in commercial fat sources are: Energy Booster® (99% fat, 86.3% saturated), Megalac® (80% fat, 55.9% saturated), Alifet® (92% fat, 67.7% saturated), Carolac® (98% fat, 61% saturated), dairy 80® (80% fat, 87% saturated), Booster Fat® (905 fat, 50% saturated), Qual Fat® Dairy Blend (41.1% saturated), Calcium-Tallowate®

(86% fat, 43.7% saturated). Energy Booster and Megalac are composed of free fatty acids and calcium salts respectively, while the others are triglycerides.

Chalupa and Ferguson (1990) reported that ruminally-inert fats, containing high proportions of palmitic and stearic acids, may not be completely inert in the rumen, because they caused small decreases in acetate:propionate ratios in some studies (Chalupa et al., 1986; Ferguson et al., 1990; Grummer, 1988; Schauff and Clark, 1989). Other studies (Grummer, 1988; Schauff and Clark, 1989) showed that calcium salts of long chain fatty acids were inert in the rumen; however, Wu et al., (1991) demonstrated that the Ca soaps may undergo biohydrogenation.

The most definitive research has been conducted with Energy Booster and Megalac. Limited scientific studies have been reported with the other ruminally inert fats.

LIPID DIGESTION AND ABSORPTION IN THE RUMINANT

LIPID METABOLISM IN THE RUMEN

Two important microbial transformations occur with lipids in the rumen: lipolysis and biohydrogenation (Jenkins, 1993). Lipolysis-after esterified plant lipids are consumed, they are hydrolyzed by lipases of microbial origin causing the release of fatty acids. Anaerovibrio lipolytica produces an extracellular lipase (Henderson, 1973) that hydrolyses acylglycerols completely to free fatty acids (FFA) and glycerol (Hawke, 1970). Glycerol is fermented and yields propionic acid. Hydrolysis of the ester bond of acylglycerols is also carried out by a number of strains of other ruminal bacteria (Jenkins, 1993).

Biohydrogenation-unsaturated free fatty acids are hydrogenated by microbes to more saturated end products, protecting microbes from toxic effects of unsaturated fatty acids. Biohydrogenation starts with an isomerization reaction that converts the cis-12 double bound in an unsaturated FA to a tran-11 isomer. The isomerase is not functional unless the fatty acid has a free carboxyl group; hence biohydrogenation must follow lipolysis. After the trans-11 is formed by action of the isomerase, hydrogenation of the cis-9 in C18:2 position occurs by a microbial reductase. Finally trans-11 C18:1 is hydrogenated to C18:0 (Jenkins, 1993).

Bacteria contain 10 to 15% lipids that are either from exogenous (uptake of dietary LCFA) and endogenous (de novo synthesis) sources (Jenkins, 1993). Fatty acids synthesized de novo by rumen microbes consist mainly of C18:0 and C16:0 in an approximate ratio of 2:1 (Knight, 1978).

On the average, 87% of the long chain fatty acids consumed are recovered at the duodenum. This small loss of fatty acid is compensated for by de novo lipid synthesis by ruminal microbes, causing a net gain of fatty acids from the rumen to the small intestine. Ruminal loss of dietary fatty acids occurs from lipid metabolism by ruminal epithelial cells, along with minimal fatty absorption into blood and degradation by microbes (Jenkins, 1994).

LIPID EFFECTS ON RUMEN FERMENTATION

Structural Carbohydrate Digestion

Lipids in ruminant diets can disrupt fermentation in rumen, reducing digestibility of non-lipid energy sources (Jenkins, 1993). Ruminal digestion of structural carbohydrates can be reduced 50% or more by less then 10% added fat (Jenkins and Palmquist, 1984). Different fat sources affect digestibilities differently. For example, unsaturated fatty acids inhibit fermentation more than saturated fatty acids (Chalupa et al., 1984; Palmquist and Jenkins, 1980). A free carboxyl group is also important for inhibition of fermentation because fatty acid derivates, such as Ca salts of long chain fatty acids (Jenkins and Palmquist 1982), fatty alcohols (Czerkawski et al., 1966), fattyacyl amides (Fotonhi and Jenkins, 1992) and triglycerides (Chalupa et al., 1984), inhibit fermentation less than free fatty acids (Jenkins, 1993). This information has been utilized to develop commercial fat sources not as depressing to rumen fermentation and cellulose digestion as are free fatty acids.

Commercial blends of animal fat and vegetable oil, despite a high degree of unsaturation, have little effect on fermentation (Palmquist, 1991; Palmquist, and Conrad 1980). The influence of fats on fermentation is associated with concentration of unsaturated free fatty acids in the rumen which is regulated by: amount and type of lipid fed, rates of lipolysis, biohydrogenation, and formation of carboxylate salts. High concentrations of triglycerides in rumen always results in an increase in concentration of unsaturated free fatty acids, particularly if lipolysis is diminished, or if biohydrogenation or formation of carboxylate salts is accelerated (Jenkins, 1993).

Mechanisms proposed to explain how lipids interfere with ruminal fermentation are: direct antimicrobial effects and, lipid coating. Fatty acids added to pure cultures of microbial bacteria inhibit microbial growth, showing direct antimicrobial effects of lipids (Galbraith et al., 1971; Henderson, 1973; Maczulac et al., 1981). Also when feed particles are added to pure cultures, 60% or more of the fatty acids become associated with feed particles (Harfoot et al.,

1974) and a lipid layer prevents adherence of cellulolytic bacteria to feed particles, thus inhibiting cellulose digestibilities (Jenkins, 1993).

Protein Metabolism

Fat supplementation to ruminants has been associated with increased N flow to duodenum and decreased ruminal ammonia concentrations, as well as increased efficiencies of microbial protein synthesis (Jenkins, 1993). The increased efficiency has been attributed to reduction of protozoal numbers in the rumen resulting in less recycling of bacterial N(Ikwnegbur et al., 1982), or to an increased dilution rate of solids in the rumen because of the added fat (Boggs et al., 1987; Czerkawskin et al., 1975).

LIPID FLOW TO THE DUODENUM

Lipids in the postruminal digesta are mainly saturated non esterified fatty acids (NEFA) of dietary and microbial origin (70%), and small but variable amounts of microbial phospholipids (10 to 20%) (Bauchart, 1993); all of which are adsorbed onto particulate matter. Triglycerides of protected fat diets may also be associated with the solid material (Bauchart, 1993). Acid conditions of abomasal and duodenal digesta (pH 2.0-2.5) cause the NEFA to be fully protonated, which maintains lipid adsorption onto the surface of particulate matter (Noble, 1981).

DIGESTION AND ABSORPTION OF LIPIDS

In the small intestine, lipid digestion occurs in a biphasic medium that consists of an insoluble particulate phase to which free fatty acids and phospholipids are attached and a soluble micellar phase containing dissolved fatty acids (Bauchart, 1993). Transfer of free fatty acids to the micellar phase occurs as digesta passes through the intestinal tract; 5% of the transfer occurs in the duodenum, 20% in the upper jejunum, 25% in the mid and lower jejunum, and 50% in the ileum (Leat and Hamsin, 1975). The process by which fatty acids are released from particulate matter involves polar detergency. Bile secretion in the duodenum favors the association of fatty acids with bile phospholipids and water, which leads to the formation of a liquid crystallin phase. With increasing pH, this phase is dispersed in the presence of bile salts to form the micellar solution (Bauchart, 1993). Conversion of bile phospholipid to lysophospholipids by pancreatic phospholipase A2 stimulates micellar solubilization of fatty acids and thus improves fatty acid passage through the unstired water layer adjacent to the microvilli of the small intestine and the subsequent absorption into the cells of the intestinal mucosa (Lough, and Smith, 1976). With conventional diets, 15 to 25% of total fatty acids are readily absorbed in the upper jejunum (pH 2.8-4.2) and 55 to 65% in the middle and lower jejunum (pH 4.2-7.6) (Bauchart, 1993). With diets containing protected lipids, lipid digestion occurs in a biphasic system, consisting of an oil phase and a micellar phase. Pancreatic lipase and colipase convert triglycerides into free fatty acids and 2-monoacylglycerols. Because the optimal pH for lipase activity is 7.5, triglyceride hydrolysis and fatty acid absorption do not take place before the mid jejunum (Bauchart, 1993).

Intestinal absorption coefficients of individual fatty acids range from 80% (saturated) to 92%(for polyunsaturated fatty acids) in diets with a low fat content (2-3% of DM). The reason for high digestibility at low fat intake is a great capacity of the bile salts and the lysophospholipase micellar system to solubilize fatty acids at the acidic conditions (pH 3.0-6.0) of the duodenal and jejunal contents (Bauchart, 1993). This low pH is because low concentrations of pancreatic bicarbonate (Leat and Harrison, 1975).

True fatty acid digestibility of dairy cows decreases progressively from 95% to 78% when fatty acid intake increases from 200g/d to 1400 g/d (about 8% of dietary DM), probably because of limited secretion and activity of pancreatic lipase and biliary lipids, which may limit lipid absorption at such high fat intakes (Bauchart, 1993). However in a review, Palmquist (1994) showed that there is no evidence that availability of bile limits digestion of fat at high intakes, and that the greatest opportunity to improve fat digestibility seems to be through manipulation of fatty acid composition in the intestine, knowing that unsaturated free fatty acids are higher in digestibility than the saturated.

Apparent fat digestibility increases linearly with increasing intake (Borsting et al., 1992; Wu et al., 1991), however at high intakes the relationship is quadratic (Palmquist, 1991; Storry, 1981; Weisbjerg et al., 1992) and true digestibilities decrease linearly (2.2%/100 g fat consumed) with increased fat intake (Palmquist, 1991).

EFFECTS OF DIETARY FAT ON FEED INTAKE

Dry matter intake must be maintained if supplemental fat is used to increase energy intake. Fat supplementation often decreases feed intake (Palmquist, 1994), probably because of inhibitory effects on rumen fermentation (Kowalczyk et al., 1977; Grummer, 1992), a slowing intestinal motility (Nicholson and Omer, 1983) or by taste or palatability (Palmquist. 1988). Decreased DMI has been reported with supplemental cottonseed (Coppock et al., 1985; Mohammed et al., 1988), cottonseed oil (Mohammed et al., 1988); raw soybeans (Mohammed et al., 1988), roasted soybeans (Mohammed et al., 1988) extruded soybeans (Anderson et al., 1984; Casper et al., 1990), soybean oil (Mohammed et al., 1988), and with whole sunflower seeds (Anderson et al., 1984).

Robinson and Burges (1990) conducted two experiments to determine effects of isocaloric substitution of corn grain with tallow or oats on DMI, ruminal fermentation and milk production. They found that high levels of fat (8.6% and 6.2% of dietary DM in experiments 1 and 2, respectively) decreased feed intake and milk production, but ruminal fermentation was not altered. Ohajuruka et al. (1991) fed Ca-LCFA and an animal vegetable blend of fat at 0, 2.5 and 5% of dietary DM and found no effect on DMI of cows. Palmquist (1991) also did not observe that DMI was affected by various fat additions; namely, an animal-vegetable blend, a Ca-soap, hydrogenated animal fat, saturated fatty acids or tallow. Schauf and Clark (1992) observed that supplementation of Ca-LCFA at 3 and 6% of DM did not affect DMI, energy intake, or ruminal fermentation in cows; whereas, supplementation of Ca-LCFA at 9% depressed DMI, altered ruminal fermentation and decreased milk yield.

Wu et al. (1993) studied effects of three supplemental fat sources (tallow, Ca-LCFA, and prilled hydrogenated fatty acids) fed at 2.5% of dietary DM on lactation performance and digestion in dairy cows (92 DIM). They found that DMI was not different by supplemental fat. In another study, Wu et al. (1994) reported effects of source and amount supplemental fat by comparing 5 diets (control, 12% WCS, 12% WCS+2.2% safflower oil, 12% WCS + 2.2% prilled hydrogenated fatty acids, or 12% WCS+4.4% prilled hydrogenated fatty acids). Lower DMI was shown for cows fed the 4.4% prilled fat diet, but there was no difference among other treatments.

Acceptability by cows is probably the most important consideration in selecting a fat supplement. Davis (1993) concluded that Ca-LCFA appears to be the only ruminally inert fat source that depresses DMI. From a regression analysis of DMI data of 20 studies where Ca-LCFA was fed as a fat supplement, he concluded that the depression effect of Ca-LCFA is more severe at higher levels of DMI. He also conducted the same type of analysis with data from 11 studies where cows were fed prilled tallow fatty acids and concluded that DMI was not affected.

Grummer et al. (1990) compared effects of different fat sources and showed that cows after 100 DIM consumed a greater percentage of their DM as fat, than those at less than 100 DIM. Following an adaptation period, DMI of diets containing Ca-LCFA was lower than that of other ruminally inert fat sources. Palmquist and Eastridge (1991) suggested that when supplemental fat is provided during early lactation, feed intake may decrease to compensate for the plasma free fatty acids released from adipose tissue. Gagliostro and Chilliard (1991) showed a DMI depression by oil infusion into the duodenum, suggesting that added fat did not decrease DMI through a ruminal or taste effect.

A summary by Palmquist (1994) shows that in the fed state, oxidation of fatty acids is limited by low circulating NEFA concentrations (Emery et al., 1992). Cows at zero energy balance oxidize less and have a lower plasma NEFA concentration then those in a negative energy balance (Palmquist, 1994). Grummer and Carrol (1991) showed that plasma NEFA also are increased by dietary fat. Studies by Lanjan and Scharres (1987) and Scharres and Lang (1986) showed that high fat diets increased hepatic fatty acid oxidation which inhibits feed intake in rats. Palmquist (1994) suggested that the depressing effects of fat on feed intake could be explained by the combined effects of mobilized and dietary fat on hepatic fatty acid oxidation.

EFFECTS OF DIETARY FAT ON MILK YIELD

Fat supplementation increases energy density of diets, and in general, increases milk and milk fat yields (Palmquist, 1994). Fat supplementation increases FCM primarily by increasing milk production (Chalupa and Ferguson, 1990). Glucose availability in the mammary gland is a major determinant of milk volume (Kronfeld, 1982), hence the increased milk volume with fat supplementation suggests a sparing of glucose from metabolism by the mammary gland. Increased extraction of LCFA from blood by mammary gland decreases de novo synthesis of short and medium chain fatty acids by a feed back inhibition of increased concentrations of long chain acyl CoA on acetyl CoA carboxylase, thus decreasing the requirement of NADPH from glucose (pentose phosphate pathway) for fatty acid synthesis (Palmquist and Jenkins, 1980).

Palmquist and Jenkins (1980) reported studies conducted by Maynard, Loosli and associates from late 1920's to mid 1940's in which a consistently greater response on milk production (2 to 10%) was shown for cows fed concentrates which provided 4 to 7% fat compared to controls fed 1 to 3% fat. Palmquist and Conrad, (1978) reported that when ether extract of diets was increased from 3 to 6% there was an increase in FCM yield of 7 to 15%. Danish workers (Danfaer, 1981; Oestegard et al., 1981) developed two curvilinear functions describing the relationship between dietary fat and milk yield, which showed that response to fat was greater for cows in early (1-12 wk) than later (11-27 wk) lactation, and that maximal response was reached at higher fat intakes. Palmquist, (1986) reported that the dairy farmer may observe an increase of 2.7 to 3.2 kg/d of milk with fat supplementation. Shaver, (1990) summarized several studies and showed that lactation responses to single sources of fat are relatively similar. Fat from whole cottonseed fed at 3 to 3.5% of the diet DM increased milk and FCM yields by .2 and 1.3 kg/d respectively, when compared to controls (Smith et al., 1981; DePeters et al., 1985; Palmquist, 1987; Horner et al., 1986). When fat was supplemented at 2.5 to 3% of DM from roasted soybean, milk yield was increased an average of 1.9kg/d compared to controls (Ruegsegger and Schultz, 1985; Driver et al., 1990; Voss et al., 1988; Faldet, 1989; Knapp and Grummer, 1990). Yellow grease fed at 3.5% of DM in two trials (DePeters et al., 1987; DePeters et al., 1989) resulted in a 4.3 kg/d increase in milk yield compared to controls. Average response of four trials (Wrenn et al., 1978; Banks et al., 1976; Storry et al., 1973; Clapperton and Steele, 1983) to feeding tallow at 4 to 5% of ration DM was 1.7 kg/d in milk and 1.9% kg/d in FCM compared to control diets. Animal vegetable blend fed at 2.5% DM increased milk yield 1.9 kg/d compared to controls (Heinrich et al., 1981; Palmquist and Conrad, 1978). Chalupa and Ferguson (1990) summarized 10 long-term studies where cows were fed .4 to .6 kg/d of Ca-LCFA and showed that 3.5% FCM was increased by 2.6 kd/d. Most of the response in FCM was accounted for by increased milk yield (2.4 kg/d).

Chan et al. (1993) reported a 1.2 kg/d increase in milk yield for cows fed 2.5% prilled fatty acids. Average response (Grummer, 1988; Schauff and Clark, 1989; Skaar et al., 1989) to feeding fat at 2.5-5% of ration DM from prilled fatty acids was .8 kg/d for milk and .6 kg/d for FCM compared to control diets.

Addition of .4 kg/d of fat from Ca-LCFA to a diet containing .5 kg of fat from WCS increased FCM 1.6 kg/d (Downer et al., 1987). However addition of only .2 kg/d of fat from Ca-LCFA did not affect milk yield (Kent and Arambel, 1988). Wu et al. (1993) compared the performance of dairy cows fed 7.2% whole cotton seed, or added tallow (2.5%), prilled fatty acids (2.5%) or Ca-LCFA (3%) and found that milk production was greater for cows fed the three supplemental fat sources (33.9, 32.9, and 34.2 kg/d) than for those fed the control diet (31.6 kg/d), but no significant differences among the fat sources were observed. Wu et al., (1994) also found that the addition of 12% whole cottonseed to a control diet did not improve milk production (32.6 vs 32.5 kg/d); however, response to addition or 2.2% safflower oil (35.0 kg/d) or 2.2% prilled fatty acids (34.3 kg/d) to diets containing 12% whole cottonseed was significant. Milk production decreased in cows fed 4.4% prilled fatty acids (33.0 kg/d).

Reports have shown residual responses of fat supplementation. Ferguson et al., (1988) reported that cows supplemented with .5 kg/d of Ca-LCFA for the first 150 days of the lactation cycle produced an additional 3.8 kg/d 3.5% FCM. Chalupa and Ferguson (1989) showed that cows continued to produce more milk (2.5 kg/d 3.5% FCM) after the Ca-LCFA were removed from the diets.

FACTORS AFFECTING RESPONSE TO DIETARY FAT

Stage of Lactation

Palmquist, (1991) challenges the concept that fat supplementation is only valuable during the energy deficit period of early lactation and several studies have shown little or no benefit from feeding fat during early lactation (Driver et al., 1990; Hoffman et al., 1991; Jerred et al., 1990; Ruegsegger and Schultz, 1985; Simas et al., 1995). Jerred et al., (1990) reported a 1.31 kg/d increase in FCM when prilled fat was fed at 5% of ration DM from 5 to 100 DIM; but cows fed supplemental fat did not respond until wk 6, and they actually produced less milk during the first 3 wk of lactation than cows fed no supplemental fat. Cows supplemented with fat produced 2 kg/d more FCM during the latter weeks of the trial than cows that were not supplemented. A delay in response to fat supplementation was reported also by Ruegsegger and Schultz, (1985); Mattial (1982) and Hoffman et al ., (1990). Palmquist, (1991) suggested that if excess dietary fat is provided during rapid adipose tissue mobilization, the cow must decrease feed intake to regulate plasma free fatty acid concentrations, which would limit intake of other nutrients.

Parity

In general, milk production response of primiparous cows to fat supplementation is less than that of mature cows (Ferguson et al., 1988; Mattias, 1982; Pitcher et al., 1991; Robb and Chalupa, 1987; Hutjens, (1990). Primiparous cows require nutrients not only for maintenance and milk production but also for growth and growth has priority over milk production. Thus, primiparous cows that are closer to mature body size are more likely to respond to supplemental fat than those that grow considerably during their first lactation.

Level of Fat Supplementation

Palmquist (1987) suggested that the upper limit of dietary fat is equivalent to the amount of fat in milk (i.e. milk yield multiplied by milk fat percentage). Hence the maximum fat level appears to be 7 to 8% total fatty acids in the diet dry matter or 16 to 20% of the metabolizable energy from fat. Wu et al., (1994) compared 12% whole cottonseed (WCS) with the WCS plus 2.2% safflower oil (7.0% FA) or 2.2% prilled fatty acids (6.9% FA) and showed increased milk production (2.5 kg/d and 1.8 kg/d respectively with the latter 2 diets); whereas 12% WCS plus 4.4% prilled fatty acids (9.1% FA) decreased milk yield, suggesting that 9.1% of DM as fat exceeded the limit for efficient use in cows producing 30-40 kg/d of milk. Grummer, (1994) suggests that supplemental fat, regardless of fat source, should not exceed 5% of ration DM.

EFFECTS OF DIETARY FAT ON MILK COMPOSITION

Milk Fat

The effect of dietary fat on milk fat content is variable, depending on the feeding regime and type of fat (Palmquist and Eastridge, 1991). Main factors affecting fat supplementation effect on milk fat content are amount and degree of unsaturation of dietary fat, and the balance between increased amounts of long chain fatty acids taken up by the mammary gland and reduced denovo synthesis (Palmquist, 1993). In general, unsaturated oils reduce milk fat percentage due to interference with rumen metabolism and fiber digestion (Palmquist and Jenkins, 1980), while oilseeds, tallow, animal-vegetable blend, and ruminally inert fats may actually increase milk fat content (Palmquist and Eastridge, 1991).

Palmquist and Eastridge (1991) summarized 50 studies and reported that when fat feeding management was optimal, a positive relationship of .172 milk fat percentage units per .45 kg of supplemental fat was found. Also, King et al., (1990) reported an increase of .33% of milk fat per kg of hydrogenated fatty acid supplement to cows on pasture.

Grummer (1991) showed that denovo FA synthesis decreases as supplemental dietary fat increased from 1 to 5% of DMI and that changes in C16 and C18 milk fatty acids were dependent on C16:C18 in the supplemental fat. About 80% of the decrease in denovo synthesis is because of increased uptake of long chain fatty acids; whereas, the other 20% is related to decreased synthesis of acetate and butyrate in the rumen, which are precursors for milk fat synthesis (Clapperton and Banks, 1985). The inhibition of denovo synthesis of fatty acids is probably by feedback inhibition on acetyl CoA carboxylase caused by increased concentrations of long chain acyl CoA groups in the mammary gland (Palmquist and Jenkins, 1980). Mattos and Palmquist, (1974) and Storry et al., (1973) showed increased butyric acid concentrations in milk fat depression because butyrate synthesis is not dependent on malonyl CoA formation. Palmquist (1993) showed that the depressing effect of supplemental fat on denovo synthesis increased as chain length increased through C12:0, which is explained by the fact that synthesis of fatty acids in the mammary gland initiates from butyric acid. Dietary fat has less of an effect on C14:0 because of the intestinal origin of some of the C14:0. Palmquist (1993) reported data on milk fat composition from trials where cows were fed basal diets and five commercial fat sources, which differed in fatty acid chain length, saturation, and chemical form. Fats were fed at 2.9 and 5.7% of total dietary DM. He concluded that all fat supplements decreased C8:0 to C15:0, but changes in C10:0, C18:0, and C18:1 were dependent on the content of C16 and C18 fatty acids in supplements. Higher fat supplementation decreased C8:0 to C15:0 fatty acids to a greater extent.

Nobel et al., (1969) reported higher milk fat yield of cows fed 10% palmitic acid compared to 10% stearic acid. Selner and Schultz (1980) concluded that the effects of unsaturated fatty acids in depressing milk fat were mediated by trans-fatty acids formed in the rumen. Teter et al., (1990) showed depressed milk fat percentages in lactating mice fed fat high in trans-C18:1. Palmquist and Eastridge, (1991) reported that in cellular studies conducted by Hansen and Krundson (1987), palmitic acid stimulated synthesis and incorporation of fatty acids into milk fat by promoting initiation of fatty acid esterification whereas oleic acid inhibited synthesis of all fatty acids except butyric acid. Hansen and Krundson (1987) postulated that C16:0 initiates glyceride synthesis (sn-1 position), which would remove newly synthesized short chain fatty acids (especially C4:0) from the synthetase (as they become esterified to sn-3); however, C18:1 competes for esterification at the sn-3 position, which would cause accumulation of newly synthesized short-chain fatty acids (less sn-3 position available to accept short-chain fatty acids from the synthetase).

Milk Protein

Feeding of supplemental fat to dairy cows has been associated with decreased milk protein concentration. Wu and Huber (1994) reviewed 49 trials involving 83 comparisons between control and fat supplemented diets, and found that magnitude of depression was similar for all types of fat. Based on the regression of adjusted percentage of milk protein concentration on percentage of dietary fat, they concluded that increasing dietary fat from 2.5 to 8% would result in a decrease in milk protein percentage.

From plotting data of Bines et al., (1978), Palmquist (1984) showed a .03 percentage unit decrease in milk protein for each increment of 100 g of fat intake from diets containing 2.1 to 10.7% fatty acids.

In a review, DePeters (1992)showed that milk protein percentage declined by .1 to .3 units with added fat (Emery, 1978). Sporndly (1986) observed that protein content of milk was correlated negatively (r=-.24) and protein yield was correlated positively (r=.31) with ether extract content of the diet. When the energy effect was removed, the correlation between EE and milk protein was improved (r=-.32), and a distinct effect of fat on milk protein was suggested. Davis (1990) stated that supplemental fat depresses milk protein content .1 to .15% for each .5 kg of supplemental fat.

DePeters et al. (1985, 1987, 1989) suggested a biological threshold for the decrease in milk protein based on a curvilinear relationship between decreased milk protein and increased dietary fat. Casein comprises 77 to 81% of total milk N, and is the milk protein fraction most subjected to depression by dietary fat (Dunkley et al., 1977; DePeters et al., 1985. 1987, 1989; Chow et al., 1990; Cant et al., 1991).

Wu and Huber (1994) suggested that since casein is synthesized de novo in the mammary gland, the reason for the decrease in casein by added fat occurs in the mammary tissue. In a review, DePeters (1992), reported that supplemental fat not only depressed total milk N, casein N and whey protein, but also increased the proportion of NPN in milk (DePeters et al., 1989; Cant et al., 1991; Chow et al., 1990; DePeters and Palmquist, 1990). Cant et al. (1993) and Casper and Schingoethe (1989) reported decreased milk essential AA with increased dietary fat, probably because the AA were being utilized for gluconeogenesis, as indicated by increased blood urea N. Moreover, the increase in plasma urea N probably accounts for the increased milk NPN (Cant et al., 1993; DePeters and Cant, 1992) resulting from increased dietary fat.

In the review by Wu and Huber (1994), of the 83 comparisons between added fat and control diets, 10 showed larger increases in milk protein yield than in milk yield when fat was added. In 11 comparisons, protein yield decreased, while milk yield increased with added fat, and in 15 comparisons, both protein yield and milk yield decreased. They also observed that decreases in milk and protein yield were often associated with cows in early lactation or at large intakes of saturated fat. Wu et al., (1993) and DePeters and Cant (1992), observed that cows in early lactation are more susceptible to a fat induced milk protein depression, which was associated with the negative energy balance. Wu and Huber (1994) using the equation developed by DePeters and Cant (1992), showed that the proportions of milk protein percentage decrease that could be explained by the dilution effect of increased milk yield averaged 53% for 45 comparisons where increases in milk protein yield were larger than, or equal to, the increase in milk yield. Wu and Huber (1994) also suggested that the decreased feed intake related to a milk protein depression in early lactation was because of a decrease in essential AA intake. Palmquist et al., (1993) suggested that supplemental fat may decrease rumen bacterial protein synthesis.

HYPOTHESES TO EXPLAIN THE FAT INDUCED MILK PROTEIN DEPRESSION

Wu and Huber (1994) summarized several hypotheses to explain the decreased milk protein concentration resulting from fat addition. One was that substitution of fat for grain energy decreases the amount of glucose precursors. However when Canale et al., (1990) fed Ca-LCFA, milk protein was decreased regardless of the amount of concentrate fed. Ranawana and Kellaway (1977) and Frobish and Davis (1977) reported no increase in milk N output with post ruminal infusion of glucose in goats and cows, respectively. Another hypotheses is that rumen microbial protein yield decreases when fat is substituted for readily available carbohydrates in the diet (Canale et al., 1990; Chow et al, 1990). A third hypotheses suggested by Wu and Huber (1994) was that the AA pool in the animal may be decreased because of greater use of AA for gluconeogenesis and that such decreases may impact on milk protein production even more then diminishing of glucose by added dietary fat would.

Palmquist and Moser (1981) showed that plasma insulin is increased in cows fed high fat diets, which would decrease uptake of AA by mammary tissue for protein synthesis. However, other studies (Horner et al., 1986; Cummins and Sartin, 1987; Kennedy et al., 1987; Mohammed et al., 1988) have shown that increased plasma insulin with fat supplementation does not consistently occurs. A lack sensitivity of mammary tissue to insulin (Laarveld et al., 1981). Brockman and Laarveld (1986) suggests that insulin does not regulate metabolism of AA in the mammary gland. Insulin resistance might increase the availability of AA to the mammary gland by directing AA away from insulin-sensitive tissues.

DePeters and Cant (1993) proposed that increased efficiency of energy utilization may explain the decreased milk protein content associated with fat supplementation. Dietary fatty acids are incorporated into milk fat, thus decreasing denovo synthesis. Such a decrease would reduce acetate utilization for FA synthesis, which could be used for tissue oxidation resulting in a sparing of glucose for lactose synthesis, and an increase in milk yield or efficiency of milk production.

DePeters and Cant (1993) observed that mammary blood flow per unit of milk produced was reduced by dietary fat. They suggested that mammary blood flow is regulated by energy supply, since estimated CO_2 production was similar for fat and non-fat supplemented diets. Decreased mammary blood flow would reduce AA supply and synthesis of milk protein, leading to the decreased milk protein concentration.

Palmquist and Conrad (1978) and Palmquist and Moser (1981) showed that FFA were higher for cows fed added fat. Reynaert et al., (1975) reported that increasing FFA concentration in blood serum decreased bST release through a negative feed back mechanism. Brockman and Laarveld (1986) reported that uptake of AA by the mammary gland is a function of both insulin and bST; the bST effect being mediated through somatomedins. Casper and Schingoethe (1989) proposed that the increase in plasma FFA associated with dietary fat supplementation would decrease somatotropin release by the pituitary, thus, decreasing mammary AA uptake. They further proposed that administration of exogenous bST would correct the depressed milk protein percentage shown in cows fed added fat. However this hypothesis was not supported by their subsequent study (Austin et al., 1991).

Reynolds (1994) suggested that supplementation of fat to isocaloric diets reduces the intake of ruminally digestible OM, even though the glucose requirement for milk synthesis is increased. Futhermore the reduced OM intake decreases rumen microbial protein and propionate synthesis thus reducing availability of protein and glucose precursors needed for milk synthesis, hence, the utilization of limiting AA for hepatic glucose synthesis may increase.

DIETARY STRATEGIES TO ALLEVIATE MILK PROTEIN DEPRESSION

Strategies to overcome the decrease in milk protein percentage associated with fat supplementation are to supplement essential AA post ruminally or to increase microbial protein synthesis in the rumen.

Several groups have proposed that the addition of rumen protected AA or high UIP to diets may help restore the milk protein depression caused by supplemental fat (Canale et al., 1990; Chow et al., 1990; Ferguson et al., 1988, 1989). Canale et al. (1990) and Chow et al. (1990) reported that feeding ruminally protected lysine and methionine alleviated the decrease in milk protein percentage in cows fed supplemental fat. DePeters and Palmquist (1990) reported similar results with cows fed fish meal. Reynolds et al. (1994) cited several studies showing consistent increases in milk protein concentration and yield with abomasal infusion of casein.

Palmquist, (1994) reported no increase in milk protein concentration when early lactation cows supplemented with 5% fat were furnished a mixture of blood and hydrolyzed feather meal as sources of UIP. In a review Theurer et al. (1995) reported no consistent changes in milk protein concentrations by supplementing diets with extra protein (regardless of rumen degradability) or with ruminally protected methionine or lysine, but extra protein may increase milk protein yield due to a greater milk yield. In their review, Wu and Huber (1994) concluded that, even though determined in short term studies with a limited number of cows, the feeding of high quality protein or methods employed to increase the supply of absorbable AA that potentially limit milk protein synthesis are the best alternatives for alleviating decreases in milk protein concentration associated with fat supplementation.

Theurer et al., (1995) suggested that altering NE_L intake and or absorption by changing the extent of dietary starch digestion in the rumen appears to be a principal means for nutritionally altering concentration and yield of milk protein in lactating dairy cows. Windschitl and Schingoethe (1994) reported positive effects of feeding supplemental whey on ruminal microbial protein synthesis. However, Schingoethe et al., (1983) reported no changed in protein percentages of milk of cows fed a blend of soy oil and dehydrated whey in place of corn and oats. Casper et al. (1990) showed no changes in milk protein percentage by addition of dried whey to diets containing soybean meal or extruded full fat soybeans, but milk protein yield increased with dried whey and extruded soybeans. Wilks et al. (1991) reported lower milk protein percentages by feeding 15% whole cottonseed, but values were restored by increased dietary starch.

Commer et al. (1993) used 24 high producing Holstein cows in early lactation to study effects of low (28%), medium (31%), and high (37%) nonstructural carbohydrate concentration in diets with added fat on milk yield and composition. They concluded that altering nonstructural carbohydrate content of the diet had no effect on milk protein content, AA supply to or uptake by the mammary gland or efficiency of utilization of AA for milk protein synthesis. Higher nonstructural carbohydrate also did not affect milk yield. In this study non structural carbohydrate was increased by replacing ground shelled corn and ground wheat for corn gluten feed.

Maiga et al. (1995) conducted a study to evaluate the lactational response of high producing cows to diets supplemented with fat that contained additional ruminally degradable carbohydrate from a molasses plus fat product and dried whey. Even though the objective of the trial was not to determine the treatment effects on milk composition, there was a tendency for the fat supplemented diets to have lower milk protein values and the higher nonstructural carbohydrates either from molasses or dried whey did not prevent fat induced protein depression.

Fat supplementation is a method to increase energy intake, however it decreases milk protein content (Wu and Huber, 1994). Increased NE_L is a mean of increasing milk protein content of milk. SFS compared to DRS increases NE_L and has been shown to increase milk protein content and yield.

Huber et al., (1993) summarized data from 8 experiments involving 175 cows and showed that steam-flaking of sorghum grain increased milk yield 10%, milk protein yield 15% and milk protein percentage 4%. One study (Simas et al., 1995) examined interactions between sorghum processing and fat supplementation and showed that steam-flaking of sorghum grain sustained milk protein concentration in early lactation cows fed high fat diets. Poore et al., (1990) and Oliveira et al., (1995) reported increasing microbial protein reaching the duodenum of cows fed flaked vs. rolled sorghum grain because of greater energy available for microbial growth from increased ruminal degradation of starch. Moore et al., (1993) reported that molar percentage of acetate in ruminal fluid were 7% lower and propionate 21% higher for cows fed steam-flaked compared with dry-rolled sorghum. Possible explanation for increased milk protein concentrations when sorghum grain is flaked rather then rolled are increased absorption of propionate for gluconeogenesis in the liver, thus sparing AA, and a greater availability of absorbed AA, because of increased microbial protein synthesis.

Some authors have suggested that niacin may alleviate milk protein depression by dietary fat (Driver et al., 1990; Erickson et al., 1989; Horner et al., 1986, 1988). However, responses have been inconsistent, and physiological mechanisms for a niacin effect are not apparent (Palmquist and Eastridge, 1991). It is hypothesized that if niacin does enhance milk protein concentration, the effect may be related to an alleviation of a ketotic status (insulin-like effect) in early lactation cows resulting in increased DMI and microbial protein synthesis (Wu and Huber, 1994).

Wu and Huber (1994) proposed that the decrease in milk protein concentration during fat supplementation relates to an inadequacy of critical AA in the mammary gland necessary for milk protein synthesis as milk volume increases, and that altering the AA composition of the digesta entering the small intestine to increase proportions of the critical AA by dietary means should aid in maintaining milk protein concentrations in cows fed supplemental fat.

FEEDING STRATEGIES FOR SUPPLEMENTAL FAT

Palmquist and Eastridge (1991) suggested that the fat metabolism of cows should be considered as the guideline for determining the amount of fat to be fed, and such an amount should be similar to the milk fat secretion. The effects of the fat source on fed intake, ruminal fermentation, milk composition, fiber digestion, digestibility of fat, as well as the economical viability should be considered when determining a strategy of addition of fats to ruminant diets (Grummer, 1994).

Lactation responses to a single sources of fat are quite similar (Shaver, 1990). Hence the least expensive fat source should be used as the first option to supplement dairy cow diets. Usually these would be oilseeds. Detrimental effects caused by the polyunsaturated fatty acids from oilseeds are not likely because the oil is encapsulated in a seed and introduced into the rumen in small amounts when fed as a TMR (Grummer, 1994).

Grummer (1994) summarized several studies where supplemental fat was added to diets already containing supplemental fat.

The studies were divided into those in which the second source of fat was granular or liquid fat. Average amount of supplemental fat prior to addition of the second fat source was 2.3% for trials in which granular fats were fed, and 2.2% for trials in which liquid fat were fed. Average level of supplementation for the second source was 2.2% for granular fats and 2.65 for liquid fats. Milk response was similar when feeding granular vs. Liquid fats (.80 vs. .65kg/d) but feeding of granular fats resulted in approximately .95 kg/d more FCM than liquid fats, which reflects the decrease in milk fat content by liquid fats, probably because of decreased fiber digestibility. Grummer (1994) summarized studies where fat was fed at or above 6% of dietary DM and caused reduction in DMI and/or milk yield (Schauff et al., 1992; Elliot et al., 1993; Wu et al., 1994). Wu et al. (1993) added 2.5% tallow, calcium salts of long chain fatty acids, or prilled hydrogenated tallow fatty acids to diets containing 7.2% whole cottonseed, and showed that fat supplementation increased yields of milk and FCM, but decreased milk protein percentage; however, there were no significant differences between fat sources. Grummer et al. (1993) added tallow at 1, 2, and 3% to diets containing 2.8% fat from whole soybeans. Tallow supplementation did not negatively affect feed intake, ruminal fiber digestion or milk fat percentage. Milk yield was not increased by supplemental tallow, but cows apparently deposited more fat on their body. DePeters et al., (1987) showed that moderate amounts of yellow grease can be added to diets containing whole cottonseed without interfering with rumen fermentation. Grummer (1994) points out that these studies suggest that tallow and grease are inert in the rumen and that at moderate quantities, they can be fed in addition to oilseeds in a TMR. However, in these two trials, cows were fed alfalfa based TMR's, which might affect response of added fat. Where cows were fed various fat sources with either corn silage, alfalfa, or corn silage/alfalfa based diets, Smith and Harris (1993) concluded that there was a greater likelihood of decreased milk and/or milk fat percentages when extruded soybeans, whole cottonseeds, and rendered animal fats were fed with corn silage-based diets than with alfalfa-based diets.

Grummer (1994) recommended that oilseeds should provide the first increment of fat in dairy cows diets. Additional fat beyond that provided by oilseeds often cannot be justified economically; where profitable, tallow or high quality greases are an appropriate second source of fat in alfalfa-based TMR's. Granular fat should be considered if DMI and milk fat content are decreased, or when using corn silage based diets. Finally supplemental fat, regardless of source, should not exceed 5% of ration DM.

STARCH UTILIZATION BY LACTATING DAIRY COWS

Starch represents about 70 to 80 % of the DM in most cereal grains. The livestock industry depends heavily upon cereal grains as sources of energy and protein for growth and lactation. The structure and composition of cereal starch and its interactions with proteins play a major role in the digestibility of starch by ruminants (Rooney and Pflugfelder, 1986).

Starch exists as highly organized granules, in which amylopectin and amylose molecules are held together by hydrogen bonding. 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 genetic variation within species. Amylopectin is a much larger, branched polymer and is the most abundant component of normal starches. It consists of linear chains of α-1,4 linked units of glucose with α-1,6 branched points every 20 to 25 glucose residues and comprises 70 to 80% of most cereal starches. Starch granules are pseudo-crystals that have organized (crystalline) and non-organized (amorphus) regions. Amylopectin, is primarily crystalline and is resistant to water entry and enzyme attack. The amorphous region (gel phase) of starch is rich in amylose and less dense than the crystalline area through which water moves freely.

Attack of amylase on starch granules begins in the amorphous region, while hydrolysis of crystalline regions occurs more slowly (Rooney and Pflugfelder, 1986).

Degradability of starch is 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, but it may be related to an amylose-restrictive role in granule swelling and enzymatic hydrolysis (Rooney and Pflugfelder, 1986).

Other factors which affect starch utilization by animals are protein bodies and the protein matrix. Electron microscopic studies have revealed the presence of protein bodies contained in the mature endosperm of cereal grains (Rooney et al., 1986). Those present in corn and sorghum are of low degradability, retarding enzymatic hydrolysis of starch due to a tight packing of starch granules and protein bodies (Delfino, 1986). Starch granules are built on protein matrices that surround the endosperm of all grains. The nature of these matrices affects digestibility of the attached starch. Digestibility of sorghum and corn protein matrices is lower then wheat, barley, and oats (Sniffen, 1980), indicating an important role of protein digestibility in sorghum feeding value. Sorghum grain is fed primarily for its energy from the starch, but the protein matrix of the endosperm must be disrupted if the nutritive potential of sorghum grain is to be realized.

GRAIN PROCESSING

Holmes et al., (1970) demonstrated that starch degradability of sorghum improved only after the protein matrix was destroyed. Grinding and dry-rolling results in little improvement in sorghum because the protein matrix and protein bodies are left intact. Disrupting and exposure of the starch granule for digestion is facilitated by heat, moisture, and pressure. McNeill et al., (1971) compared different methods of processing sorghum and concluded that any method that disrupts the protein matrix increases starch utilization.

Starch granules undergo gelatinization when sufficient energy is applied to break the intramolecular hydrogen bonds in crystalline areas. During gelatinization, the starch granules absorb water, swell, exude part of the amylose, and become more susceptible to enzyme degradation. Gelatinization commences in the amorphous areas, but penetration of heat and moisture into the crystalline regions occurs more slowly. The process is synergistic, in that the stress generated by swelling of the amorphus areas aids in disrupting the crystallites. Heat, moisture, and mechanical action are used in combination to process starchy materials. Steam-flaking involves movement of water and heat into the kernel, causing swelling of starch. Rolling the hot, moist grain tears apart some of the swollen granules, forming a paste that binds the material into a strong flake. Hence, the surface area and enzyme susceptibility of the starch are greatly increased by steam-flaking.

DIGESTION AND ABSORPTION OF STARCH

RUMINAL STARCH DIGESTION

The rumen is the principal site of starch digestion in ruminants. Microbial digestion of starch in the rumen results in production of VFA, which are the major energy source for ruminants. The amount of energy extracted from grain starch is dependent mainly upon the rate and extent of digestion in the rumen (Theurer, 1992).

Amylolitic and dextrinolytic ruminal bacteria hydrolyze starch to maltose and some glucose molecules, that are fermented rapidly by saccharolytic bacteria in the rumen (Fahey and Berger, 1988). Two moles of pyruvate are produced from each hexose, with the concomitant production of two ATP and two reduced $NADH_2$. The ATP generated is the primary energy source for growth and maintenance of bacteria. The pyruvate is further fermented to VFA, CO_2, and CH_4. Acetate, propionate and butyrate are the principal end products of rumen fermentation, and are major energy sources for the host animal.

MICROBIAL SYNTHESIS IN THE RUMEN

Microorganisms depend on availability of carbon skeletons and energy (ATP) for protein synthesis (Nocek and Tamminga, 1991). Ruminant systems that predict ruminal microbial synthesis are usually based in fermentable OM, however rumen microorganisms mostly grow on carbohydrates or secondary products of carbohydrate digestion. Organisms that degrade fatty acids grow too slowly to maintain an active microbial population and only the glycerol portion of the fat is fermentable (Nocek and Tamminga, 1991). Fermentation of amino acids is an uneconomical process for microbial growth. Often microbial growth on amino acids alone is not feasible because ATP synthesis is slow when this substrate is utilized (Nocek and Tamminga, 1991). Systems that predict microbial yield based on carbohydrate digestibility in the rumen are better predictors of microbial yield than fermentable OM (Hvelplund and Madsen, 1985). Ruminal starch availability is probably the most important factor affecting microbial growth.

VFA ABSORPTION AND METABOLISM

Reynolds et al., (1988) reported that VFA plus BHBA could account for 78% of measured net portal drained viscera (PDV) energy absorption, 64%of measured net PDV energy flux, 53% of ME, and 98% of milk energy in lactating dairy cows. VFA are extensively metabolized by the PDV, rates of VFA production overestimate net VFA absorption (Britton and Krehbiel, 1993). In a review, Britton and Krehibel (1993) reported that absorption of acetate represented 70% of ruminal production indicating that near 30% of the acetate is utilized by gut tissues. Acetate is carried by portal circulation to the liver which shows no net metabolization of acetate. Acetate is the main precursor for lipogenesis in ruminants. Acetate is the precursor of short chain milk fatty acids up to and including some of the palmitic acid. Reynolds et al. (1994), reported that around 50% of propionate produced in the rumen is utilized by gut tissues and more then 90% absorbed by PDV is removed by the liver in lactating dairy cows (Reynolds et al., 1988). Propionate is the major substrate for gluconeogenesis in ruminants. Kronfeld et al., (1968) calculated that the mammary gland of a cow producing 30 kg/d of milk (1.5 kg of lactose) requires about 2.2 kg/d of glucose. Nearly all the glucose required for milk production is synthesised in the liver from gluconeogenic precursors (Theurer et al., 1992). Butyrate is converted (90%) to BHBA and acetoacetate during absorption thought the rumen wall (Britton and Krehbiel, 1993), resulting in very low butyrate levels in portal blood. The PDV releases and utilizes ketone bodies (Reynolds et al., 1994). BHBA accounts for more than 80% of the ketones formed, with the remainder comprised of acetoacetate and acetone. Ketones are oxidized in cardiac skeletal muscle, and are used for fatty acid synthesis by adipose and mammary gland tissues. Other uses of VFA include metabolism by gut tissue, as fuel for respiratory metabolism (oxidation to CO_2), some propionate is converted to lactate and perhaps alanine, and acetate is incorporated in mucosal and other PDV lipids (Reynolds et al., 1994).

FACTORS AFFECTING RUMINAL STARCH DEGRADABILITY

Many factors influence ruminal starch degradability, including grain source, as well as grain processing, particle size, and chemical treatment of grains. Pertaining to grain source, a summary of several in vivo studies (Nocek and Tamminga, 1991), showed different ruminal starch degradabilities for ground wheat (89.3%), rolled barley (87.9%), rolled oats (84.0%), ground corn (76.4%), and rolled sorghum (64%). Herrera-Saldana et al., (1990) reported that in situ ruminal starch digestibilities for oats, wheat, barley, corn and sorghum were 98, 95, 90, 62 and 49%, respectively. Ratio of amylose:amylopctin influences starch degradability. Guibot and Mercier (1985) showed that waxy corn starch, with a lower amylose content, was more degradable than starch from normal corn varieties. Sullins and Rooney (1975), compared waxy to normal varieties of sorghum and found that waxy starch varieties are more digestible than normal sorghum grains. The lower digestibility for the high amylose grain varieties may be related to the amylose's restrictive role in granule swelling and/or to orientation of amylose molecules towards the inside of amylopectin crystallites, causing an increase in intramolecular hydrogen bonding which would limit swelling and enzymatic hydrolysis (Rooney and Pflugfelder, 1986). Starch degradability is also affected by protein bodies and the protein matrix in grains. It was hypothesized (Hibberd et al., 1982; Delfino, 1986) that protein bodies retard enzymatic hydrolysis of corn and sorghum starch due to tight packing of starch granules with the protein bodies.

Processing is generally associated with improvement in efficiency of nutrient utilization of grains and can be divided into physical and chemical methodologies (Nocek and Tamminga, 1991). Physical processing methods usually consist of braking, craking, grinding, rolling, or pelleting of dried grains. Physicochemical modifications involve the application of heat and water, which hydrate and swell amorphous and crystalline structures of the starch granule. This alteration in structure enhances amylolytic digestion by both microorganisms and pancreatic enzymes. Processing might also disrupt the protein matrices and protein bodies that prevent starch digestion, allowing greater accessibility to enzymatic digestion (Nocek and Tamminga, 1991). Most processing methods increase ruminal starch digestion, which usually increases percentage of starch digested in the small intestine (Owens et al., 1986). Theurer (1986) reported that the average ruminal starch degradation of dry-rolled sorghum (DRS) and steam-flaked sorghum (SFS) for beef cattle was 57 and 76%, respectively. In dairy cows, Oliveira et al. (1995) showed that ruminal starch degradability was 59.7% for DRS compared with 81.3% for SFS; Poore et al. (1993) reported ruminal starch degradabilities of 48 and 74% for DRS and SFS, respectively; Chen et al. (1994) showed increased ruminal starch digestibilities for DRS compared with SFS (59 vs 78%).

Ruminal starch digestion is affected by particle size and outflow from the rumen. Reduction in particle size occurs through mastication, rumination, microbial fermentation, and detrition by ruminal muscular activity (Nocek and Tamminga, 1991). The reduction in particle size increases the surface area and makes the particle more fragile and accessible for microbial digestion. Ewing and Johnson (1987) showed that decreasing corn particle size resulted in increased rates of passage from the rumen. Feed particle size and reduction rate can influence density, which influences rate of passage out of the rumen. Rates of passage of the solid and liquid phases will strongly influence whether or not starch will be digested in the rumen or escape to the lower gut (Nocek and Tamminga, 1991).

Several chemical treatments have been applied to grain to alter starch flow and digestibility in the digestive tract of ruminants. Fluharty and Loerch (1989) reported that addition of 1 and 2% formaldehyde decreased ruminal corn starch digestion 30 and 41.5%, respectively, but total tract digestion was not affected. Oke and Loerch (1989) showed that treatment of corn with formaldehyde decreased ruminal starch digestion 38%. There was increased intestinal digestion, but total tract starch digestibility was not affected. Nocek and Tamminga (1991) reported a shift in the site of starch digestion from the rumen to the small intestine with ammoniated barley and Moran (1986), showed higher daily excretion of fecal starch from cows fed alkali-treated oats compared with whole and rolled oats.

POST RUMINAL STARCH DIGESTION AND FLOW

Nocek and Tamminga (1991) summarized results of 14 production studies and reported that total starch intake was correlated positively with intake of ruminally degradable starch (RDS), ruminal escape starch, and total tract and intestinal digestibilities of starch. Ruminal and total tract digestibilities of starch were highly correlated, and total tract digestibilty was influenced to a greater extent by ruminal rather than postruminal digestibility. They also concluded that as intake increases more starch is digested postruminaly; however as postruminal starch flow increased, starch digestion, as a percentage of that entering the small intestine, decreased.

Starch digestion in the small intestine in ruminants is the same process as in nonruminants. Intestinal break down of starch to glucose requires enzymes capable of cleaving both α-1-4 and α-1-6 glucosidic linkages (amylose and amylopectin). Pancreatic amylase breaks amylose to maltriose and maltose, which are hydrolyzed by intestinal maltase to glucose (Coombe and Siddon, 1973). Amylopectin hydrolysis is completed in the small intestine by isomaltase (Siddons, 1968) because pancreatic amylase has no α-1-6 glucosidic activity.

ENZYMATIC ACTIVITY

Owens et al. (1986) suggested that low enzymatic activity for starch hydrolysis and inadequate access of enzymes to starch granules limit intestinal starch digestion in ruminants. Mayers and Orskov (1974) suggested the cause to be low amylase and inadequate isomaltase activities. Also they showed that capacity of small intestine of sheep to digest and absorb raw starch was 100 to 200 g/d, compared with 200 to 300 g/d for gelled starch and 300 to 400 g/d for glucose, they too, attributed the poor digestion of raw starch to limited pancreatic amylase secretion. Limits to postruminal starch digestion were also demonstrated by infusion of starch and glucose into the duodenum (Orskov, 1986; Owens et al., 1986) and abomasum (Huntington and Reynolds, 1986) of cattle. Infusion of amylase in steers did not increase starch digestion (Remillard and Johnson, 1984). Steers fed diets of 80% whole corn or 80% DRS digested 2 to 2.5 kg of starch per day from the small intestine, indicating a large capacity of the small intestine for starch digestion (Theurer, 1986). McCarthy et al. (1989) reported that up to 4.8 kg of corn starch was digested in the small intestine of dairy cows suggesting that amylase activity may not limit intestinal starch digestion. Nocek and Tamminga (1991) indicated that the efficiency of starch digestion decreases as the amount delivered to the small intestine increases despite the large capacity of the small intestine to digest starch.

GLUCOSE ABSORPTION AND METABOLISM

In ruminants, the mechanism of D-glucose transport across the small intestine is by an active, sodium-dependent pump. Kreikemeier et al. (1991) reported that net glucose absorption and glucose flow to the ileum increased with increased abomasally infused glucose and starch, suggesting that hydrolysis occurred at a faster rate than absorption. They further suggested that there is a saturation of the active transport system or some other barrier (physical or chemical) to glucose absorption. However, at higher levels of infusion, passive transport appeared to predominate, because glucose absorption rose slightly with infusion rate and data is consistent with calculations of Owens et al. (1986), which suggest the there is no plateau in the amount of starch disappearing from the small intestine.

The fate of glucose resulting from starch digestion in the small intestine is not well understood. It has been assumed that efficiency of carbohydrate utilization is greater when glucose is absorbed directly as a result of postruminal starch digestion, rather then when dietary C is absorbed as VFA, AA, and other glucose derivatives. However, net PDV appearance of glucose is usually negative or negligible in lactating dairy cows (Reynolds et al., 1994). This does not mean that no glucose is absorbed, but it does suggest that absorption of glucose into the portal vein is exceeded by arterial glucose utilization. The fate of the C digested from starch that does not appear in the portal blood has not been clarified. Possible explanations for the glucose disappearance are:

fermentation in the intestine, conversion to lactate, oxidation to CO_2 , incorporation into visceral lipids, use in synthesis of mucupolysaccharides and triacylglycerides (Reynolds et al., 1994).

Nocek and Tamminga (1991) summarized data from several studies employing PDV or MDV catheterization techniques with dairy cattle to evaluate effects of digestible energy intake (DEI), ruminally degradable starch (RDS), and intestinally digestible starch (IDS) intake on appearance of glucose, propionate, and lactate in PDV. They showed a negative relationship between DEI and carbohydrate intake versus net portal appearance of glucose. However, propionate and lactate were positively correlated with intake parameters. They suggested that, as DEI increases, there may be a greater oxidative drain on glucose for gut metabolism to process and metabolize nutrients.

DIGESTION OF STARCH IN THE LARGE INTESTINE

Starch passing to the large intestine is subjected to further microbial fermentation. Starch fermentation in the large intestine results in production and absorption of VFA's, synthesis of microbial protein from N in digesta, and entrance into the large intestine from the blood of increased amounts of urea N. The microbial N is excreted in the feces resulting in a reduction in the urinary N and apparent digestibility of dietary N (Orskov, 1986). A large flow of undigested nutrients to the post ruminal digestive tract is thought to occur in high producing dairy cows during early lactation because of high concentrate intake, resulting in increased fecal starch that is available for fermentation in the large intestine (Plegge, 1986). Oliveira et al. (1994) demonstrated that cows fed DRS had more starch and CP and a lower pH in their feces than those fed SFS, suggesting that significant amounts of starch was fermented in the large intestine. Fermentation of large amounts of starch in the large intestine is usually undesirable.

LACTATIONAL RESPONSE OF DAIRY COWS TO RUMINAL STARCH DEGRADABILITY

Effect of site of starch digestion on lactational performance of cows is a major indicator of the usefulness of manipulating site of starch digestion. Until recently, the influence of site of starch digestion on milk production in dairy cows had not been adequately defined (Theurer, 1991) and sorghum grain had not been extensively used in commercial dairies because producers have generally felt that performance of cows fed high sorghum diets was inferior than fed corn or barley (Theurer, 1992). Also, flaking of sorghum grain reduced milk fat content, which is still the base for pricing milk in some regions.

Recent studies at the University of Arizona have defined effects of increasing ruminal starch degradability by steam flaking of sorghum grain on lactational performance of dairy cows. Poore et al. (1993) compared SFS to DRS in cows fed alfalfa hay or wheat straw diets, and showed that steam-flaking increased total starch digestibility, milk and milk protein yields, but it decreased milk fat percentage without altering milk fat production. Moore et al. (1992) fed DRS and SFS (390 and 290 g/l) and found that steam flaking improved starch digestibility, milk and milk protein yields over dry-rolling; however, flaking at 290 g/l reduced DM intake, FCM, and milk protein yield compared to the 390g/l flake. Oliveira et al. (1993) fed steam rolled corn (480 g/l), dry-rolled sorghum, steam-flaked sorghum (360 g/l) and a mixture 50% dry-rolled and 50% steam flaked sorghum. The DRS diet had the lowest starch digestibility; whereas, SFS was highest. Milk protein percent and yield were higher for cows fed SFS than DRS. Theurer et al. (1991) fed either DRS or SFS at 43 and 35% of the diet DM and demonstrated increased starch digestibilities and milk and milk protein production from flaking of sorghum, with benefits from flaking greater for the high grain diets. Again, milk fat yield increased with flaking, though milk fat was decreased. Estimated NE_L for SFS was 20% higher than DRS. Digestible starch intake and efficiency of milk production increased 12 and 7% respectively. Chen et al. (1994) compared effects of steam flaking sorghum and corn and showed that compared with rolling, flaking of both grains increased yields of milk, milk protein and fat, and the protein content in milk, but differences tended to be greater for sorghum then for corn. In an other study Chen et al. (1993) substituted steam flaked sorghum for a commercial grain mix containing steam-rolled corn, rolled barley, wheat mill run and ground beet pulp. Yields of milk and milk protein and percentages of milk protein and SNF was increased linearly as sorghum increased from 15 to 45% of diet DM, though highest yields were at 30%. Chen et al.(1993) tested the effect of a sorghum specific enzyme added to DRS and SFS on lactational performance of cows. They reported that compared to dry-rolling, steam-flaking increased yield of milk and milk protein, but enzyme addition did not affect any performance measures.

To summarize these studies: SFS increased milk yield (8-10%) and milk protein yield (10-16%) compared to DRS. Flaking of sorghum grain depressed milk fat percentages, but milk fat yield was not altered. SFS increased digestibible starch intake and efficiency of feed utilization.

Nocek and Tamminga (1991), also summarized several production trials of cows fed starch of different rumen degradabilities, and concluded that maximum milk production was associated with the greatest intake of both ruminally and intestinally degradable starch, and that increasing post ruminal starch digestion may increase glucose availability slightly, but does not consistently increase milk or milk protein yield.

EFFECT OF STEAM-FLAKED SORGHUM ON SITE AND EXTENT OF STARCH DIGESTION

Improved lactational performance with SFS appears to be consistent with increases in ruminal and total tract digestibilities of starch, digestible starch intake, and flow of bacteria to the small intestine. Oliveira et al. (1995) determined effects of sorghum grain processing on site and extent of digestion of nutrients. SFS, DRS, steam-rolled corn and a 50:50 mixture of SFS and DRS were fed at 42.9% of DM. Ruminal and total tract digestibilities of starch were higher for SFS then for DRS diets (81 vs. 59% and 97 vs. 85%, respectively). Cows fed SFS also tended to more efficiently convert dietary CP digested in the rumen to bacterial crude protein (BCP), and to have higher BCP flow to the duodenum. Poore et al. (1993) studied the effect of sorghum grain processing on site and extent of starch digestibility. Ruminal and total tract starch digestibilities for SFS were 74 and 98% respectively, compared with 48 and 83% for DRS. Flow of BCP was 25% higher for cows fed SFS than DRS. Molar proportions of acetate were lower, and propionate higher for SFS compared with DRS diets. However, acetate to propionate ratios were higher for cows fed DRS than for SFS.

Theurer (1991) summarized several studies at the University of Arizona comparing SFS to DRS diets and concluded that SFS increased total starch digestion an average of 22% (96 vs 79%) as well as digestible starch intake, probably because of increased ruminal starch degradation (78 vs 54%) in cows fed SFS.

EFFECTS OF STEAM-FLAKED SORGHUM ON MILK PROTEIN CONTENT

As previously mentioned, studies at the University of Arizona (Moore et al., 1992; Oliveira et al., 1993; Poore et al., 1993; Simas et al., 1995; Theurer et al., 1992; Chen, 1994) showed that percentages and yields of milk protein increased when lactating dairy cows were fed SFS compared to DRS. Possible explanations for increased milk protein concentrations resulting from steam-flaking compared with dry-rolling of sorghum are increased microbial protein yield and increased absorbed propionate for gluconeogenesis in the liver, thus sparing AA from gluconeogenesis. Wu et al. (1994) tested this hypothesis by infusing glucose into the rumen or propionate into the duodenum and measuring the milk protein content. Milk protein percentage was higher (2.88 vs. 2.72%) for cows ruminally infused with glucose then for those infused in the duodenum with propionate. For the respective treatments, duodenal flows were 2.11 and 1.76 kg/d for microbial protein and 3.44 and 2.73 kg/d for total CP (or 85 and 74% of CP intake). These data demonstrate that increased propionate availability for gluconeogenesis and possible sparing of essential AA for milk protein synthesis did not increase milk protein content. However ruminal infusion of glucose, which tended to increase ruminal protein synthesis, did increase the protein percentage of milk.

Theurer (1995) summarized several reports and concluded that maximizing NE_L absorption or ruminal starch fermentation in lactating dairy cows appear to be effective methods for increasing concentration and yield of milk protein. Many studies have demonstrated that steam-flaking of corn or sorghum grain for lactation diets consistently increases milk protein content and yield, while improving efficiency of milk production.

SUMMARY AND NEEDED RESEARCH

Fat supplementation is a method to increase energy intake, however it decreases milk protein content (Wu and Huber, 1994). The mechanism of milk protein depression caused by supplemental fat is still unsolved. Wu and Huber (1994) concluded that, even though determined in short term studies with a limited number of cows, methods employed to increase the supply of absorbable AA that potentially limit milk protein synthesis are the best alternatives for alleviating decreases in milk protein concentration associated with fat supplementation. Theurer et al., (1995) suggested that altering NE_L intake and or absorption by changing the extent of dietary starch digestion in the rumen appears to be a principal means for nutritionally altering concentration and yield of milk protein in lactating dairy cows. Increased NE_L is a mean of increasing milk protein content of milk. SFS compared to DRS increases NE_L and has been shown to increase milk protein content and yield. Limited studies have varied supplemental fat and type of non structural carbohydrate. Therefore the interrelations between supplemental fat and non structural carbohydrates might be of interest for the future. Such research is very important because milk pricing system now favors milk protein more than milk fat. More research is needed to determine effects of combining fat sources and levels and different starch degradabilities on rumen fermentation, nutrient flow, and ruminal microbial protein synthesis and on milk composition. Data on additive effects of fat supplementation and degradable starch at peak lactation, as well as the level of fat supplementation that would be most beneficial is limited. More research is needed on interactions of widely differing fat sources (in degree of saturation and FA composition) and starch degradabilities on lactation performance. These questions led us to plan and conduct the research reported herein.

CHAPTER 3

INFLUENCE OF SORGHUM GRAIN DEGRADABILITY AND FAT SUPPLEMENTATION ON RUMEN FERMENTATION AND NUTRIENT PASSAGE TO THE DUODENUM OF DAIRY COWS

ABSTRACT

Four lactating Holstein cows fitted with T-type duodenal cannulae were used in a 4X4 latin square for 17 d periods. Treatments were : 1) dry-rolled sorghum, no added fat (DC); 2) dry rolled sorghum plus 2.5% Ca salts of long chain fatty acids (Ca-LCFA) (DF); 3) steam-flaked sorghum, no added fat (SC); and 4) steam-flaked sorghum plus 2.5% Ca-LCFA (SF). Added fat increased the fatty acid (FA) content in diets from 2.9 to 4.8%. Average milk yield determined for the last five days of each period increased 5 kg/d for cows fed fat (F) compared to unsupplemented © cows. Compared to dry-rolled (DRS), steam-flaked sorghum (SFS) diets decreased rumen ammonia concentrations 14%. The SC diet resulted in higher total ruminal VFA, propionate and butyrate, and the lowest C2:C3 ratios. Fat supplementation increased propionate, isobutyrate and 2-methylbutyrate on the DRS diets but decreased total VFA, propionate and total VFA on SFS diets. Ruminal pH and acetate concentration were not affected by diets. Diets with SFS had higher ruminal (73.4 vs. 52.1%) and total tract (99.1 vs. 95.0%) starch digestibilities than those

with DRS. Ruminal and total tract ADF and NDF digestibilities were lower for diets with SFS than with DRS. Duodenal flows of total CP and microbial protein were not affected by diets. Increasing ruminal starch degradation with steam-flaking of sorghum increased ruminal propionate, butyrate, and total VFA, and decreased C2:C3 ratio when fat was not added to the diets. Fat supplementation increased milk production, increased propionate and total VFA concentration and decreased C2:C3 ratio in diets containing DRS.

INTRODUCTION

Addition of fat to diets for lactating cows increases energy intake in support of higher milk yields (Palmquist, 1984). Added fat has been shown to have beneficial effects on lactational performance but it decreases the protein content of the milk (Wu, Z. and J.T. Huber, 1994). Studies conducted at the University of Arizona (Moore et al., 1992; Oliveira et al., 1993; Poore et al., 1993; Simas et al., 1992; Chen et al., 1994) showed that the percentage and yield of milk protein increased when lactating dairy cows were fed steam-flaked compared with dry-rolled sorghum grain. Moreover, steam-flaking overcame decreases in milk protein in early postpartum cows associated with dietary fat supplementation (Simas et al., 1995).

Compared with dry-rolling, steam-flaking of the sorghum grain increased ruminal starch degradability in lactating cows fed 40% sorghum grain diets from approximately 50 to 80% (Oliveira et al., 1992; Poore et al., 1991; Theurer, C.B. 1992). Increased ruminal starch degradation by growing steers fed 77% steam-flaked sorghum grain diets resulted in higher absorption of acetic and propionic acids.

Greater degradation of starch in the rumen increased microbial protein synthesis (Oliveira et al., 1992; Poore et al., 1993). Possible explanations for the increased milk protein concentration when sorghum grain is flaked rather than rolled are increased absorbed propionate for gluconeogenesis in the liver, thus sparing AA from gluconeogenesis and absorption of AA because of the increased microbial protein yield, both allowing a greater uptake of AA by the mammary gland for milk protein synthesis.

Objectives of this study were to determine effects of sorghum grain processing and fat supplementation on ruminal fermentation and nutrient passage to the duodenum of lactating cows and to help clarify why steam-flaked sorghum might overcome the milk protein depression associated with addition of dietary fat (Simas et al., 1995).

MATERIAL AND METHODS

Four lactating Holstein cows from the University of Arizona

Dairy Research herd were fitted with T-type cannulas in the proximal duodenum and were used in a 4X4 Latin square design for four periods of 17 d (12 d of adjustment and 5 d of collection) each. Treatments were: 1) dry-rolled sorghum (DRS), no added fat; diet DC; 2) DRS plus 2.5% fat; DF; 3)steam-flaked sorghum (SFS); no added fat; SC; 4) SFS plus 2.5% fat; SF. Diets contained 36 to 40% grain (Table 1). To obtain dry-rolled sorghum, the whole grain was passed thought a roller mill with rolls adjusted for a coarse grinding (570 g/l). Steam flaked sorghum was prepared by steaming the whole grain for 40 to 50 min in a steam chamber and then flaking to a density of 320 g/l. Supplemental fat was substituted for grain and contained Ca-soaps of palm fatty acids (Ca-LCFA);(Megalac®; Church and Dwight Co., Inc., Princeton, NJ). Ca-LCFA contained 82% fatty acids and 16% Ca. The sorghum grain was mixed into the TMR the same day as processed. Other ingredients in diets were alfalfa hay, whole cottonseed, cottonseed hulls, molasses, buffer, minerals and vitamins.

Cows were housed in individual pens with shade and fed the TMR once daily at 1600h to allow ad libitum consumption. Feed offered was adjusted to 10% in excess of appetite and orts were weighed daily to determine feed intake. Cows were milked twice daily at 0500 and 1700 h.

Ammonia sulfate labeled with ^{15}N (180 mg/d) was used as a bacterial marker for estimation of microbial protein synthesis. The label was added twice daily directly through the ruminal cannula for the last 7 d of each treatment period (2 d prior to during the 5 d of collection).

Milk yields were recorded daily, and milk samples were taken from each milking during the collection period and composited daily. Milk samples were analyzed at the Arizona DHI Laboratory for protein, fat, lactose, and total solids by infrared procedures (Foss 360; Foss Technology, Eden Prairie, MN); SNF was determined by difference.

Samples of feed offered were taken from each of 3 TMR mixes and were composited for the entire experiment. Orts were sampled daily during the last 5 d of each period and were composited by period. Ruminal samples (≈ 25 ml) were collected from each cow at 2 h intervals during the last day of the collection period and measured for pH immediately after each collection; they were then stored at -4 °C for later analyses of VFA and ammonia N. Duodenal digesta (≈ 500 ml) was sampled every 4 hours with sampling times delayed 1h/d so that samples represented every hour of a 24 h period. Duodenal samples were composited from each individual cow for each period and were kept frozen at -4 °C for subsequent analyses. A second duodenal sample (≈ 250 ml) was also collected at each sampling for separation of bacteria. Aliquots of these samples were centrifuged at 2000 X g for 15 min to remove protozoa and feed particles. The supernatant was then centrifuged at 18,000 X g for 15 min to separate bacteria. The bacterial pellet was frozen and then placed in a freeze dryer at -5 °C after which it was ground to a fine powder with mortar and pestle. Fecal grab samples (≈ 250 ml) were collected twice daily from each cow during the last 4 d of each period and composited for the period. Duodenal and fecal samples were kept at - 4°C until processed for chemical analysis.

Samples of TMR, orts, duodenal digesta, and feces were dried at 50 °C for 48 h and ground in a cyclone mill (Udy Co., Fort Collins, CO) equipped with a 1 mm screen and analyzed for DM (100 °C for 24 h), OM (550 °C for 10 h), CP (N-C-S Analyzer, NA 1500; Carlo Erba Strumentazione, Strada Rivoltana, Italy), starch (Poore et al., 1991), and ADF, NDF, and acid detergent lignin according to the methods of Robertson and Van Soest (1981). Long chain FA were determined by the method of Sukhija and Palmquist (1988) using GLC (model 5890, equipped with a flame ionization detector and auto injector model 7673A; Hewllet-Pakard, Palo Alto, CA). Apparent ruminal, postruminal, and total tract nutrient digestibilities were calculated from ratios of nutrients to lignin in feed, duodenal digesta, or feces. Content of ^{15}N in duodenal digesta and bacteria were determined by mass spectrometry as described by Pessarakli and Tucker (1985). Enrichment of ^{15}N in digesta divided by enrichment in bacteria estimated the fraction of the total N from bacterial protein. Ruminal samples were analyzed for NH_3N (Chaney and Marbach, 1962) and VFA (Erwin et al., 1961) using GLC (Model 3300; Varian Associates Inc., Walnut Creek, CA).

Data were subjected to statistical analysis for treatment effects according to the GLM of SAS (1985) using the following model:

$$Y_{ijkl} = \mu + T_i + P_j + C_k + e_{ijkl}$$

where:

Y_{ijkl} = observation,

μ = overall means,

T_i = treatment effect,

P_j = period effect,

C_k = cow effect, and

e_{ijkl} = random error.

Because of large variations encountered in duodenal flow studies (Herrera-Saldana et al., 1990; Poor et al., 1993;

Oliveira et al., 1993), differences were declared significant at $p<.10$ and trends at $p<.20$.

RESULTS AND DISCUSSION

Dietary content of ADF, NDF, and starch were within NRC (1989) recommendations for lactating dairy cows (Table 1). Crude protein content was slightly higher than expected for all diets, probably because the cottonseed was ammoniated to destroy aflatoxin. Fatty acid content of the diets was increased from 3.0 to 4.8 with addition of fat (Table 2).

Intakes of DM were not significantly affected by treatment but fat addition tended to increase DMI (Table 3). Some studies (Chen et al., 1994; Simas et al., 1995) showed that cows fed diets with steam-flaked sorghum consumed more then those fed with dry-rolled sorghum while others (Moore et al., 1992; Poore et al., 1993; Santos et al., 1994; Theurer et al., 1991) reported that cows fed dry-rolled diets had higher DMI then those fed steam-flaked sorghum. In the present study no effect of sorghum grain processing was observed. Fat supplementation did not depress DMI as observed previously (Simas, 1995) in early lactation cows which also were fed Ca-LCFA. The tendency for increased DMI in this study was probably because of the later stage of lactation and lower levels of production of cows in this study.

Steam flaking of sorghum grain compared to dry rolling did not effect yields of milk, FCM, milk protein, or milk fat but fat supplementation increased yields of milk and FCM. There was no significant effect of fat supplementation in milk composition, but because of the higher milk yield, added fat increased yields of milk protein and milk fat.

Rumen pH was low and similar among diets (Table 4), probably because of the high starch intake (7.4 kg/d). Concentration of ammonia was lower for SFS than DRS diets, suggesting greater microbial utilization of NH_3. Concentrations of total VFA, propionate and butyrate, were highest for the SC diets. Fat supplementation to the SF diet decreased molar concentrations of VFA, whereas propionate and isobutyrate and 2-methylbutyrate were increased by fat addition to DRS diets. Ratio of C2:C3 was decreased by SFS and by fat supplementation to DRS. Rumen parameters data suggest a more active rumen fermentation with SFS diets; however, fat supplementation to DRS diets also stimulated fermentation.

Increased ruminal VFA concentrations were associated with greater ruminal starch degradation. Moore et al. (1992) reported that molar percentage of acetate in ruminal fluid was 7% lower, and propionate 21% higher ($P<.01$), for cows fed steam-flaked compared with dry-rolled sorghum diets, resulting in lower acetate to propionate ratios. Chen et al. (1994) reported increases in both acetate and propionate with SFS diets. In this study acetate was numerically and propionate significantly increased with SFS without fat supplementation. Despite some differences between studies, most report increased concentrations in the rumen of acetate and propionate, which would supply more absorbed energy for milk synthesis. Theurer et al. (1991) reported a significant increase in VFA absorption in steers fed 77% steam-flaked compared with dry-rolled sorghum grain, suggesting that site of starch digestion has an important impact on the efficiency of energy absorption and utilization. Furthermore, Theurer et al. (1991) and Chen et al. (1994) reported that NE_L of sorghum grain was increased 21 to 25%, respectively, when steam-flaked compared to dry-rolling. The reason fat supplementation increased ruminal VFA in cows fed dry-rolled sorghum and apparently inhibited VFA on steam-flaked diets is unclear. Possible explanations are a decrease in ruminal fiber digestibility for the DF compared with the DC diet, and the numerically higher starch intake for the DF than the DC diet.

Flow of total OM and bacterial OM to the duodenum was not affected by diets (Table 5); however, steam-flaking of sorghum decreased feed OM reaching the duodenum because of the higher rumen fermentable OM (RFOM) for the flaked diets. Steam-flaking also increased post ruminal and total tract OM digestibilities. The reason for the higher OM digestibilities with the flaked diets is the greater digestibility of the starch fraction.

Flaking of sorghum grain significantly increased ruminal and total tract starch digestibilities (Table 6). Starch flow to the duodenum was about 70% higher for dry-rolled than for steam-flaked sorghum (3.62 vs. 2.10 kg/d). Digestibilities of starch in the rumen (73.4 vs. 52.1%), total tract (94.5 vs. 99.1%) and postruminal tract (96.4 vs. 89.6%) were higher for cows fed steam-flaked than dry-rolled sorghum. The lower ruminal and total tract starch digestibilities with DRS compared with SFS are consistent with previous studies by Poore et al. (1993) (48 vs. 78% for ruminal and 83 vs 98% for total tract digestion); Oliveira et al. (1995), (60 vs 81% and 85 vs 97%) and Chen et al., (1994) (59 vs 78% and 92 vs. 96%).

Owens et al. (1986), suggested that starch digested in the small intestine is used more efficiently in metabolism than that digested in the rumen. However, Theurer (1986) showed higher efficiency of weight gains in beef cattle with greater digestion of starch in the rumen compared with the postruminal digestive tract. Lactational studies (Chen et al., 1994; Chen et al., 1993; Poore et al., 1993; Oliveira et al., 1993.; Simas et al., 1992; Theurer et al., 1991) have shown improved milk and milk protein yields with steam-flaked compared with dry-rolled sorghum grain. Results from Poore et al. (1993), Oliveira et al. (1995), and Chen et al. (1994), together with results from the present study, suggest that total tract starch digestibility is more positively related to starch digestion in the rumen than in the small intestine.

Intakes of CP were not significantly different between diets (Table 7). Flow of total CP and microbial CP (MCP) to the duodenum were similar for all diets. Efficiency of microbial protein yield (MCP/RFOM) was decreased for steam-flaked compared with dry-rolled sorghum (16.8 vs. 14.2). Ruminal apparent and true CP digestibilities were not significantly affected by treatment. Postruminal and total tract CP digestibilities were higher for steam-flaked compared to dry-rolled sorghum, but the reason for this occurred is unclear. Poore et al. (1992), reported a significant increase in microbial protein flow to the small intestine when cows were fed steam-flaked compared with dry-rolled sorghum. Oliveira et al. (1995), also observed a trend toward increased microbial protein flow to the duodenum in cows fed steam-flaked vs. dry-rolled sorghum, although total CP flow was not altered.

In support of this study, Chen et al., (1994) reported no increase in microbial protein flow of cows fed steam-flaked compared with dry-rolled sorghum. Cameron et al. (1991) reported that supplying additional ruminal degradable starch (12.5% of dietary DM) to cows consuming 38% ground corn did not significantly increase microbial protein flow to the small intestine. McCarthy et al. (1989) compared a barley-based with a corn based diet and showed no increase in microbial N flow to the duodenum of cows fed barley, a more ruminally degradable starch source. However, DMI of cows fed barley were lower than of cows fed corn.

The wide variability among the metabolic studies discussed is probably because of differences in the type of diet, stages of lactation, DMI, and feeding methods; but, more importantly, because of a lack of a more precise techniques for measuring microbial protein flow and synthesis.

Wu et al. (1993), showed higher microbial protein flow to the duodenum and milk protein content in cows fed dry-rolled sorghum ruminally infused with glucose, compared with those duodenally infused with propionate. Infusions were calculated to approximate the increased ruminal energy supplied from the larger amount of ruminally degraded starch resulting from feeding a diet containing 40% steam-flaked compared with dry-rolled sorghum. In the present study, microbial protein flow to the small intestine was not increased with a more ruminally fermentable starch source; and despite the higher propionate concentrations, no increase in the milk protein content of milk was observed.

Steam-flaking of sorghum decreased digestibilities of both ADF and NDF, probably because the greater fermentation of starch stimulated higher numbers of amylolytic relative to cellulolytic organisms, even though no decrease in rumen pH was observed.

CONCLUSION

Fat supplementation increased milk yield, stimulated ruminal fermentation of diets with dry-rolled sorghum grain, and depressed ruminal VFA concentrations in diets containing steam-flaked sorghum grain. Steam-flaking compared with dry-rolling of sorghum grain greatly increased both ruminal and total tract digestibilities of starch and increased VFA production (when fat was not supplemented). Steam-flaking of sorghum grain did not increase microbial protein flow to the small intestine in contrast with some previous studies and milk composition was not affected by type of grain or fat supplementation.

Table 1. Ingredient and Nutrient composition of diets.

	Diet[1]	
Item	DC/SC	DF/SF
Ingredient % of DM		
Sorghum grain[2]	40.6	37.1
Soybean meal	7.5	8.5
Megalac	...	2.5
Alfalfa Hay	34.0	34.0
Whole cottonseed	10.0	10.0
Cottonseed hulls	3.0	3.0
Molasses, dried	1.5	1.5
Minerals and vitamins[3]	2.0	2.0
Buffer[5]	1.4	1.4
Composition of DM		
OM	91.1	91.5
Starch	30.6	29.4
CP	21.5	20.5
ADF	21.3	20.3
NDF	28.9	28.1
Ne_l, Mcal/kg[4]	1.60	1.68

[1] DC = dry-rolled sorghum, no supplemental fat; SC = steam-flaked sorghum, no supplemental fat; DF = dry-rolled sorghum with supplemental fat; SF = steam-flaked sorghum with supplemental fat.
[2] Dry-rolled or steam flaked
[3] A commercial supplement containing 33.3% calcium carbonate, 38.7% dicalcium phosphate, 17.3% trace mineralized salts, and 10.7% vitamins A, D_3, and E (calculated to furnish 50,000 IU of vitamin A, 5,000 IU of vitamin D_3, and 250 mg of vitamin E/d per cow).
[4] $NaHCO_3$, 1%; MgO, .4%.
[5] Calculated from on NRC(1989).

Table 2. Fatty acid (methyl esters) content and composition of diets (DM basis).

	Diet[1]			
Fatty acid	DC	DF	SC	SF
Content, % of DM	2.9	4.7	3.0	4.9
	g/100 g of methyl esters			
C16:0	31.0	41.8	30.1	42.2
C18:0	4.1	4.4	4.0	4.2
C18:1	21.6	25.2	17.9	21.6
C18:2	21.5	13.6	23.5	13.2
C18:3	2.5	2.2	3.8	3.1
Other	19.3	12.8	20.7	15.7

[1] DC = dry-rolled sorghum, no supplemental fat; SC = steam-flaked sorghum, no supplemental fat; DF = dry-rolled sorghum with supplemental fat; SF = steam-flaked sorghum with supplemental fat.

Table 3. Dry matter intake, milk yield, and milk composition of cows fed experimental diets.

	Diet[1]					P<	
Item	DC	DF	SC	SF	SEM	G	F
DMI, kg/d	21.5	23.6	21.7	24.4	1.4	.72	.14
Milk yield, kg/d	27.0	33.1	28.7	32.5	1.7	.75	.03
3.5% FCM, kg/d	23.0	29.9	23.8	28.9	1.9	.96	.02
Milk protein, %	2.90	2.85	2.84	2.80	.05	.29	.43
kg/d	.75	.94	.77	.90	.06	.93	.03
Milk fat, %	2.72	2.91	2.61	2.84	.17	.60	.26
kg/d	.70	.96	.70	.91	.08	.08	.03
Milk lactose, %	4.71	4.70	4.71	4.72	.06	.95	.98
Milk SNF, %	8.19	8.14	8.12	8.09	.06	.42	.57
FCM/DMI	1.14	1.32	1.10	1.19	.13	.57	.34

[1] DC = dry-rolled sorghum, no supplemental fat; SC = steam-flaked sorghum, no supplemental fat; DF = dry-rolled sorghum with supplemental fat; SF = steam-flaked sorghum with supplemental fat.
[2] G = grain processing effect; F = fat supplementation effect.

Table 4. Ruminal pH and metabolites in cows fed experimental diets.

	Diet[1]				
Total	DC	DF	SC	SF	SEM
pH	5.87	5.84	5.83	5.80	.08
Ammonia N, mg/dl	21.8^{ab}	23.2^{a}	19.4^{b}	19.5^{b}	1.3
VFA, mM					
Total	143.8^{b}	150.1^{ab}	158.2^{a}	146.4^{b}	5.0
Acetate	92.1	92.7	97.2	93.0	3.3
Propionate	29.1^{b}	33.2^{a}	36.8^{a}	31.1^{ab}	1.4
Butyrate	17.0^{ab}	17.8^{a}	18.1^{a}	16.4^{b}	.7
Isobutyrate	1.37^{b}	1.52^{a}	1.43^{ab}	1.42^{ab}	.07
2-Methylbutyrate	1.00^{b}	1.17^{a}	1.09^{ab}	1.09^{ab}	.08
Valerate	2.23	2.55	2.38	2.37	.19
Isovalerate	1.04	1.14	1.08	1.06	.07
$C_2:C_3$	3.37^{a}	2.94^{b}	2.79^{b}	3.01^{b}	.10

[ab] Means not sharing the same superscript are different (P<.10)
[1] DC = dry-rolled sorghum, no supplemental fat; SC = steam-flaked sorghum, no supplemental fat; DF = dry-rolled sorghum with supplemental fat; SF = steam-flaked sorghum with supplemental fat.

Table 5. Effects of sorghum grain processing and fat supplementation on digestibility of OM by lactating cows.

	Diets[1]					P<[2]	
Item	DC	DF	SC	SF	SEM	G	F
OMI, kg/d	19.6	21.7	19.8	21.9	1.4	.87	.16
OM flow, kg/d							
Duodenal OM	12.09	12.66	10.04	11.43	1.30	.25	.48
Bacterial	3.80	4.50	3.54	4.50	.54	.81	.17
Feed	8.29	8.16	6.51	6.93	.81	.11	.86
RFOM[3]	11.32	13.41	13.30	15.24	.80	.05	.04
Fecal OM	7.50	7.48	5.15	6.06	.65	.03	.51
Digestibility, %							
Ruminal							
Apparent	39.4	41.7	50.3	49.2	3.5	.04	.86
True[4]	59.4	62.1	68.2	69.6	2.4	.01	.43
Post ruminal	37.1	40.3	46.5	46.3	3.9	.09	.7
Total Tract	62.2	65.7	73.8	72.7	1.9	.01	.57

[1] DC = dry-rolled sorghum, no supplemental fat; SC = steam-flaked sorghum, no supplemental fat; DF = dry-rolled sorghum with supplemental fat; SF = steam-flaked sorghum with supplemental fat.
[2] G = grain processing effect; F = fat supplementation effect.
[3] OM truly fermented in the rumen.
[4] Corrected for microbial OM.

Table 6. Effect of sorghum processing and fat supplementation on digestibility of starch by lactating cows.

	Diets[1]					P<[2]	
Item	DC	DF	SC	SF	SEM	G	F
Starch intake, kg/d	6.85	7.60	7.62	7.60	.41	.37	.40
Starch flow, kg/d							
Duodenal	3.65	3.59	2.16	2.03	.46	.01	.84
Fecal	.47	.25	.07	.07	.07	.01	.18
Digestibility, %							
Ruminal	51.0	53.2	73.0	73.7	4.1	.01	.72
Postruminal	87.4	91.8	96.0	96.7	1.8	.01	.21
Total tract	93.4	96.5	99.1	99.1	.94	.01	.20

[1] DC = dry-rolled sorghum, no supplemental fat; SC = steam-flaked sorghum, no supplemental fat; DF = dry-rolled sorghum with supplemental fat; SF = steam-flaked sorghum with supplemental fat.
[2] G = grain processing effect; F = fat supplementation effect.

Table 7. Effect of sorghum grain processing and fat supplementation on duodenal flow and digestibility of crude protein by lactating cows.

	Diet[1]					P<[2]	
Item	DC	DF	SC	SF	SEM	G	F
CP intake, kg/d	4.61	4.79	4.66	5.06	.30	.61	.38
Duodenal flow of CP, kg/d							
Total	3.43	3.73	3.23	3.76	.46	.86	.40
Microbial	1.99	2.19	1.85	2.20	.28	.83	.36
MCP/RFOM[3]	17.7	16.2	13.9	14.4	1.9	.19	.82
Digestibility, %							
Ruminal							
Apparent	26.0	23.2	31.2	25.9	5.9	.52	.52
True[4]	69.9	68.3	71.1	69.5	2.7	.69	.57
Postruminal	42.5	49.8	56.9	57.4	5.3	.08	.48
Total tract	59.2	61.5	71.3	68.4	2.5	.01	.9

[1] DC = dry-rolled sorghum, no supplemental fat; SC = steam-flaked sorghum, no supplemental fat; DF = dry-rolled sorghum with supplemental fat; SF = steam-flaked sorghum with supplemental fat.
[2] G = grain processing effect; F = fat supplementation effect.
[3] OM truly fermented in the rumen.
[4] Corrected for microbial OM.

Table 8. Effect of sorghum grain processing and fat supplementation on fiber digestibility by lactating cows.

	Diet[1]					P<[2]	
Item	DC	DF	SC	SF	SEM	G	F
Intake, kg/d							
NDF	7.52	6.84	5.77	6.87	.51	.14	.69
ADF	4.52	4.78	4.68	4.98	.29	.57	.39
Digestibilities,%							
Ruminal							
NDF	50.3	45.2	36.1	37.2	3.0	.01	.5
ADF	50.9	38.2	39.1	39.5	2.9	.11	.07
Total							
NDF	51.9	42.2	33.9	40.8	3.6	.03	.7
ADF	52.3	36.4	30.2	38.9	2.1	.003	.14

[1] DC = dry-rolled sorghum, no supplemental fat; SC = steam-flaked sorghum, no supplemental fat; DF = dry-rolled sorghum with supplemental fat; SF = steam-flaked sorghum with supplemental fat.
[2] D = sorghum grain processing effect; F = fat supplementation effect.

CHAPTER 4

INFLUENCE OF SORGHUM GRAIN PROCESSING IN DAIRY COWS FED VARYING LEVELS OF FAT ON PERFORMANCE AND NUTRIENT DIGESTIBILITIES

ABSTRACT

Forty Holstein cows averaging 85 DIM were assigned to 5 dietary treatments for 56 d to determine effects of rumen starch degradability and amount of supplemental fat on milk yield, milk composition, and nutrient digestibilities. Diets were: 1) dry-rolled sorghum grain, no added fat; 2) diet 1 plus 2.5% prilled fatty acids; 3) steam-flaked sorghum grain, no added fat; 4) diet 3 plus 2.5% prilled fatty acids; 5) diet 3 plus 5% prilled fatty acids. The 2.5 and 5% added fat increased the content of fatty acids in the diets from 4.5 to 7 and 9.5% respectively. To determine digestibilities, diets were mixed with .1% Cr_2O_3 during the last 14 d of treatment and fecal grab samples were taken 2X daily for 5 d. Milk yield was increased an average of 2.0 kg/d by steam-flaking of sorghum grain and supplemental fat at 2.5% increased milk yield by 2.4 kg/d. However, when fat was supplemented at 5%, milk production was numerically decreased compared with 2.5%. Steam-flaking of sorghum grain decreased DMI 12% and increase in efficiency of feed utilization (FCM/DMI) 11% when 2.5% fat was fed. Milk composition was not affected by treatments;

however, milk protein yield and efficiency of conversion of dietary protein to milk protein were increased by flaking of sorghum grain. Supplementation of fat at 5% did not improve lactational performance, but increased BW gain. Fat supplementation did not affect digestibilities of OM, ADF, or NDF. Digestibilities of starch were increased (98.2 vs. 92.6%) with steam-flaked sorghum grain compared with dry-rolled. Steam flaking of grain also increased fatty acid digestibilities (80.0 vs. 75.5%). Steam flaking of sorghum grain and 2.5% added fat both improved lactational performance, and effects were additive. Supplementation of 5% fat to diets containing 7.5% whole cottonseed appeared excessive for high producing cows near peak lactation.

INTRODUCTION

Fat addition to diets helps meet energy requirements of high producing dairy cows without causing metabolic disorders often associated with large intakes of grain. Although yields of milk and milk fat have been increased by supplemental fat (Palmquist, 1984), high fat diets have been associated with lowered milk protein concentrations (Wu and Huber, 1994). Studies conducted at the University of Arizona (Moore et al., 1992; Poore et al., 1993b; Simas et al., 1992; Theurer et al., 1991; Chen et al., 1994), have shown increased milk protein percentages and yields in cows fed stem-flaked compared with dry-rolled sorghum grain, mainly because of increased ruminal (Oliveira et al., 1992; Poore et al., 1993; Chen, 1994) and total tract digestion of starch (Oliveira et al., 1993; Poore et al., 1993b; Simas et al., 1992; Theurer et al., 1991; Chen et al., 1994). When fat was added at 2.5% of DM to either dry-rolled or steam-flaked sorghum diets from 1 to 13 wk postpartum, milk protein content was only depressed in the dry-rolled diet (Simas et al., 1992). However, beneficial effects of fat supplementation were not observed because of decreased DMI. It was hypothesized that the depression in milk protein content often observed when fat is supplemented to cows responsive to fat addition would be alleviated by steam-flaked sorghum. The objective of this study was to determine the effects of steam flaking of sorghum grain on milk protein content and yield in dairy cows fed fat supplemented diets near peak lactation. A high fat diet also was compared to assess response to a large amount of fat in cows fed steam-flaked sorghum.

MATERIALS AND METHODS

Forty cows averaging 85 DIM were fed the normal herd diet (containing 38% alfalfa hay, 12% ammoniated whole cottonseed, 4% cottonseed hulls and 46% concentrate mix) during a 14 d pretreatment period for assignment to 8 outcome groups and random allotment to the following dietary treatments for 57 d:

1) dry-rolled sorghum, no added fat (DR); 2) DR + 2.5 % prilled fatty acids[1] (E), (DRE); 3) steam-flaked sorghum, no added fat (SF); 4) SF + 2.5% E (SFE); and 5) SF + 5% F (SFEE). Diets were formulated to meet nutrient requirements of lactating cows yielding 40 kg/d of milk (NRC, 1989) for CP, NE_L, vitamins and minerals (Table 1). Cows were housed in group pens of 8 each (randomly distributed across treatments) and were provided shade in the pen and over the manger. Individual cows were fed TMR once daily for ad libitum intake through electronically controlled Calan gates (American Calan, inc., Northwood, NH). Orts were weighed daily just prior to feeding and feed offered was adjusted daily to about 10% in excess of appetite. Cows were weighed for 3 consecutive days at the beginning and end of the trial and daily body weight changes were computed. Cows were milked 3 times daily at 0800, 1600, and 2400h and milk yields were recorded at each milking. Milk samples from individual cows were collected and composited from 3 consecutive milkings once weekly. Milk was analyzed for fat, protein, lactose, and SNF contents by infrared procedures at the Arizona DHIA laboratory in Phoenix. Samples of each TMR were collected at weekly intervals and composited for the entire experiment. Total tract digestibilities of DM, OM, CP, ADF, NDF, starch and FA were determined during the last 14 d of the lactation trial when all diets were mixed with .1% Cr_2O_3 as an indigestible marker.

For the last 5 d of the trial, TMR was sampled once daily, and total orts were collected from each cow. Fecal grab samples were taken twice daily (0800 and 2000) and frozen at -10 ° C. Samples of TMR, orts and feces were composited by treatment for the 5 d of collection.

Feed DM was determined at 100 ° C. Samples of TMR and orts were air dried and fecal samples were dried at 50 ° C. Dried samples of TMR, orts and feces were then ground in a cyclone mill (Udy CO., Fort Collins, CO) to pass a 1 mm screen and analyzed for DM (100 ° C for 24 h), OM (550 ° C for 10 h), CP by AOAC (1990) using a digester (Tector®; Hogans, Sweden) and N autoanalyser (Bran and Luebbe, Analyzing Technologies, Elmsford, NY), ADF and NDF according to Robertson and Van Soest (1981), starch by the method of Poore et al. (1991), and total fatty acids by the method of Sukhija and Palmquist (1987) using a GLC (model 5890, equipped with a flame ionization detector and auto injector model 7673A; Hewlett-Packard, Palo Alto, CA). Analysis of Cr in TMR, orts, and feces was according to the method of Fenton and Fenton (1979). Actual intake of Cr_2O_3 and nutrients was adjusted for amounts determined in orts. Digestibilities of nutrients were calculated from ratios of concentration of Cr_2O_3 in feed consumed to that of feces.

Data were analyzed by GLM procedures of SAS (1985) as a randomized block design, with the 14 d pretreatment period used for covariate adjustment of DMI, milk yield, milk composition, milk component yields and, efficiencies according to the following statistical model:

$$Y_{ijk} = M + B_i + T_j + Cov_k + E_{ijk}$$

where

M = overall mean

B_i = bloking effect

T_j = treatment effect

Cov_k = covariate effect

E_{ijk} = random error

Digestibility data were also analyzed by the GLM procedures of SAS (1985) using a similar model but the covariate effect was excluded.

[1]Energy Booster-100® furnished by Milk Specialties CO., Dundee, IL

RESULTS AND DISCUSSION

All nutrients were provided in accordance with NRC (1989) guidelines for lactating cows. Diets which were not supplemented with fat contained 3% FA, higher than normal diets because of the inclusion of 7% whole cottonseed. Fat supplementation at 2.5 and 5% of diet DM increased the FA content to 5.4 and 7.7%, respectively. DMI was lower ($P<.05$)

for SF and SFE than for DR and DRE (Table 2), similar to trends reported by Moore et al., (1992); Oliveira et al., (1992); Poore et al., (1991); Theurer et al., (1991), and significant effects by Santos et al., (1993) and (1994); but they are in disagreement to others (Simas et al., 1995; Chen et al., 1994). The reason for lower intakes of flaked compared with rolled grains may be because of a more active rumen fermentation and borderline rumen acidosis. Lack of change in DMI with fat supplementation is consistent with results of Chan et al.(1992), Wu et al.(1993), and Eastridge and Firkins (1991), who used cows of similar DIM as in this study; but in contrast with our previous study with immediately postpartum cows fed Ca salts of long chain fatty acids (Simas et al., 1995).

Compared with rolling, flaking of sorghum grain increased yields of milk 2.0 kg/d ($P<.08$), and milk protein 75 g/d ($P<.04$). Milk protein content was not significantly increased by flaking compared to rolling, which is in disagreement with some studies (Moore et al., 1992; Oliveira et al., 1993; Poore et al., 1993b; Simas et al., 1992; Theurer et al., 1991), but not with Santos et al., (1993) and (1994), who also noted decreased DMI in cows fed flaked compared with rolled sorghum. Generally, a decrease in DMI would result in decreased milk protein synthesis; but this did not occur with flaked compared with rolled sorghum grains because of the higher energy content of the flaked sorghum, as supported by 17% greater efficiency in conversion of dietary protein to milk protein for flaked vs. rolled sorghum diets. Increased microbial protein synthesis resulting from higher rumina digestion of sorghum starch might explain the increased efficiency of milk protein synthesis (Poor et al., 1993; Oliveira et al., 1995).

Fat supplementation at 2.5% of diet DM to both the DR and SF diets increased yield of milk (P<.04) an average of 2.4 kg/d. The increase in milk yield with about 2.5% fat supplementation is consistent with previous studies (Wu et al. 1993; Wu et al. 1994) in cows fed similar diets. These findings support the summary by Palmquist (1984), who started that supplemental fat usually increases milk yield. Fat content of milk did not differ between treatments but, yields of fat and FCM were higher (P<.05) for cows receiving 2.5% fat than for those not supplemented with fat because of higher milk yields..

Percentages of milk fat were lower then expected (3.03% for all treatments), probably because of the early stage of lactation and high milk yield of the cows. Also, the alfalfa hay in the TMR was chopped to an average particle size of 5 to 10 cm length. Content of NDF (31 to 33%) was adequate to maintain good fermentation in the rumen (NRC, 1989). Efficiency of feed utilization (FCM:DMI) tended to be higher ($P<.10$) for SF and SFE compared to DR and DRE. Fat supplementation at 2.5% of diet DM also resulted in increased ($P<.01$) feed efficiency.

Supplementation of fat at 5% of diet DM did not increase milk yield. These results are consistent with a previous study (Wu al., 1994) and support current recommendations (Grummer, 1994) that supplemental fat regardless of source not exceed 5% of ration DM. Body weight gains were numerically higher for the high fat than for other diets, lactation energy requirements were probably being met by diet containing steam-flaked sorghum grain and the 2.5% supplemental fat, so additional energy was partitioned towards body fat.

Similar to findings of previous studies (Poore et al., 1993; Simas et al., 1995; Oliveira et al., 1993), flaking compared with rolling increased ($P<.01$) digestibility of starch. Difference in starch digestibilities between flaked and rolled sorghum grain (98.2 vs. 92.6%) were in agreement with Chen et al.(1994) (98 vs. 91%), but less than those shown by Oliveira et al. (1993), Poore et al. (1993), and Simas et al. (1995), which averaged 96% for steam-flaked and 77% for dry-rolled sorghum grain. The reason for the higher digestibility of DRS in this studies is not clear.

Digestibilities of DM, CP, starch, and ADF were not affected by fat supplementation. However NDF digestibilities were numerically lower when fat was added to the diets. The ruminally inert nature of the fat supplement used the relatively low content of FA in the diets (5.4 and 7.7) might have been responsible for the lack of greater differences in nutrient digestibilties, in agreement with other studies (Grummer, 1988; Jerred et al., 1990; Palmquist, 1990; Schauff and Clark, 1989; Wu et al., 1993). Digestibility of total FA was not affected by fat supplementation, even when fat was supplemented at 5% (7.7% FA). Palmquist (1991), showed that apparent digestibility of FA was maximal when dietary fat content was approximately 4%, which is close to diets with 2.5% supplemental fat. Storry (1981) and Khorasani et al. (1992) suggested a quadratic effect of fat intake on apparent digestibility of FA. Eastridge and Firkins (1991) reported lower digestibility of FA at 5% than at 2% fat supplementation, but total fat content of diets seems to be a major factor controlling FA digestibility.

CONCLUSIONS

Steam flaking of sorghum grain compared with rolling improved milk and milk protein yields. Fat supplementation at 2.5% of

DM to increase fatty acid content from 3.0 to 5.4 % increased yields of milk and FCM. Milk protein percentages were not significantly depressed by fat supplementation nor were they increased by flaking of sorghum grain. However, efficiency of conversion of dietary protein to milk protein was increased by flaking of sorghum grain. Cows producing extremely high levels of milk respond positively to both steam flaking of sorghum grain and supplementation of dietary fat, with the effects being additive for 2.5% supplemental fat. Addition of 5% fat to increase fat content to about 7.7% appears excessive for cows producing 44 to 46kg/d of milk.

Table 9. Ingredient and nutrient composition of diets DM.

	Diets[1]				
Item	DR	DRE	SF	SFE	SFEE
<u>Ingredient, % of DM</u>					
Alfalfa hay	38.3	37.3	38.3	37.3	36.4
Cottonseed hulls	5.0	4.9	5.0	4.9	4.8
Whole cottonseed	7.1	6.9	7.1	6.9	6.8
Sorghum grain[2]	35	34.1	35.0	34.1	33.2
Soybean meal	9.9	9.7	9.9	9.7	9.4
Dried molasses	1.5	1.5	1.5	1.5	1.4
Buffer[3]	1.4	1.4	1.4	1.4	1.3
Mineral and vitamin mix[4]	1.8	1.8	1.8	1.8	1.7
Prilled tallow fatty acids	---	2.5	---	2.5	5.0
<u>Nutrient, % of DM</u>					
OM	90.8	90.8	90.8	91.1	90.8
CP	18.4	17.9	18.7	18.5	17.7
ADF	22.8	23.2	22.8	21.4	21.5
NDF	31.8	30.9	32.8	30.9	30.1
Starch	26.8	25.9	27.4	27.1	26.7
NE_l[5] (Mcal/kg)	1.56	1.67	1.56	1.67	1.75

[1] Dietary treatments: DR = dry-rolled no added fat, DRE = dry-rolled plus 2.5% prilled fatty acids, SF = steam-flaked no added fat, SFE = steam-flaked plus 2.5% prilled fatty acids, SFEE = steam-flaked plus 5% prilled fatty acids.
[2] Steam Flaked or dry rolled
[3] 1.1% $NaHCO_3$, .4% MgO
[4] Containing calcium carbonate, .50%; biphosphate, .58%; trace mineral salts, .26%, and vitamins A, D and E, .16% (calculated to furnish 50,000 IU of vitamin A, 5,000 IU of vitamin D, and 250 mg of vitamin E/d per cow).
[5] Estimated from NRC

Table 10. Fatty acid (methyl esters) content and composition of diets (DM %)

	Diet[1]				
Fatty acid	DR	DRE	SF	SFE	SFEE
Content, % of DM	3.0	5.4	2.9	5.4	7.7
	(g/100 g of methyl esters)				
C14:0	.9	1.3	.9	1.4	1.7
C16:0	26.6	30.1	25.7	30.8	34.2
C18:0	4.3	17.3	3.8	17.6	27.3
C18:1	18.4	12.5	16.2	12.7	11.2
C18:2	27.1	21.5	28.3	21.2	13.1
C18:3	4.1	4.1	5.5	3.6	2.2
Other	18.6	13.2	19.6	12.7	10.3

[1]Dietary treatments: DR = dry-rolled no added fat, DRE = dry-rolled plus 2.5% prilled fatty acids, SF = steam-flaked no added fat, SFE = steam-flaked plus 2.5% prilled fatty acids, SFEE = steam-flaked plus 5% prilled fatty acids.

Table 11. Effect of sorghum grain processing and fat supplementation on DMI, and lactation performance of dairy cows.

	Diet[1]						P<[2]		
Item	DR	DRE	SF	SFE	SFEE	SEM	G	F	5%
DMI, kg/d	28.9	30.8	26.7	26.1	26.8	1.7	.05	.73	.57
Intake, %BW	4.44	4.43	4.38	4.40	4.40	.04	.37	.74	.95
Milk, kg/d	42.4	44.8	44.4	46.7	44.8	1.1	.08	.04	.23
3.5% FCM, kg/d	38.7	41.6	40.6	43.1	41.0	1.0	.10	.01	.17
FCM/DMI	1.44	1.51	1.46	1.67	1.50	.05	.10	.01	.03
Milk Fat, %	3.01	3.09	2.97	3.04	3.00	.08	.56	.39	.72
kg/d	1.25	1.37	1.32	1.41	1.34	.04	.24	.02	.23
Milk Protein %	2.78	2.80	2.83	2.81	2.76	.04	.54	.97	.40
kg/d	1.17	1.24	1.25	1.31	1.23	.04	.04	.10	.15
g/kg CP intake	220	232	264	293	285	22	.01	.27	.36
Milk Lactose, %	4.78	4.74	4.82	4.70	4.71	.03	.96	.02	.69
Milk SNF, %	8.15	8.17	8.21	8.11	8.05	.06	.92	.53	.49
Initial BW, kg	6.09	6.13	6.10	6.18	6.45	23	.89	.78	.44
BW change, kg/d	.55	.40	.58	.48	.96	.23	.81	.60	.14

[1] Dietary treatments: DR = dry-rolled no added fat, RE = dry-rolled plus 2.5% prilled fatty acids, SF = steam-flaked no added fat, SFE = steam-flaked plus 2.5% prilled fatty acids, SFEE = steam-flaked plus 5% prilled fatty acids.
[2] G = DR+DRE vs. SF+SFE; F = DF+SF vs. DRE+SFE; 5%= SFE vs. SFEE

Table 12. Effect of sorghum grain processing and fat supplementation on nutrient digestibilities of dairy cows.

	Diet[1]							P<[2]	
Item	DR	DRE	SF	SFE	SFEE	SEM	G	F	5%
DM	70.8	66.7	70.2	69.8	72.7	1.9	.55	.26	NS
OM	71.8	67.4	71.1	70.9	73.3	1.9	.47	.25	NS
CP	72.0	67.8	70.4	69.9	72.7	1.9	.89	.22	NS
Starch	92.1	93.1	98.0	98.4	97.8	.72	.01	.54	NS
ADF	56.9	49.9	49.9	46.7	51.8	4.3	.25	.25	NS
NDF	60.5	53.4	56.7	52.1	56.7	3.7	.49	.12	NS
Fatty acids	78.2	72.8	76.2	83.9	79.5	2.2	.04	.60	.16

[1] Dietary treatments: DR = dry-rolled no added fat, DRE = dry-rolled plus 2.5% prilled fatty acids, SF = steam-flaked no added fat, SFE = steam-flaked plus 2.5% prilled fatty acids, SFEE = steam-flaked plus 5% prilled fatty acids.

[2] G = DR+DRE vs. SF+SFE; F = DF+SF vs. DRE+SFE; 5%= SFE vs. SFEE.

CHAPTER 5

INFLUENCE OF RUMEN STARCH AVAILABILITY AND FAT SOURCES IN LACTATION PERFORMANCE AND NUTRIENT DIGESTIBILITIES IN HIGH PRODUCING DAIRY COWS.

ABSTRACT

Forty-eight lactating cows averaging 81 DIM were grouped into 8 blocks based on the 14 day pretreatment milk production and assigned to the six groups in a 2X3 factorial arrangement of treatments. Factors were: type of sorghum grain processing (dry-rolled vs. steam-flaked fed at 34% DM in alfalfa-based diets) and type of fat (fed at 2.5% of DM in a TMR as cottonseed oil, tallow, or prilled fatty acids). Compared with dry-rolled, steam-flaking of sorghum did not affect milk production, fat percentage or yield, but it did increase milk protein percentage, body weight gains and estimated NE_L (22.6%). Fat source did not affect lactation response but, prilled fatty acids tended to decrease DMI compared with tallow and cottonseed oil. Steam-flaking compared to dry-rolling of sorghum grain increased DM, OM, CP, and starch digestibilities regardless of fat source. Prilled fat diets were lower than those with cottonseed oil or tallow for digestibilities of DM, and OM. This study showed that steam flaking of sorghum increased milk protein content, body weight gain, and estimated NE_L of sorghum grain regardless of dietary

fat source.

INTRODUCTION

Ruminal inert fats are used to increase energy density of diets without having negative effects on rumen fermentation (Palmquist, 1984; Wu et al. 1991). However, these fat sources are often more expensive than natural sources of fats. Wu et al., (1993) showed that responses in milk yield were not significantly different (2.1 kg/d) when tallow, Ca salts of long chain fatty acids (Ca-LCFA), or prilled fatty acids (PFA) were furnished at 2.5 % of DM in diets containing 7.2% whole cottonseed, eve though response to Ca-LCFA was numerically lower. Moreover, Wu et al., (1994) showed no difference in lactation response to prilled fatty acids or safflower oil when added at 2.2 % of DM to alfalfa-based diets containing 12% whole cottonseed. Supplementation of fat to dairy diets often result in a milk protein depression, regardless of fat source (Wu and Huber, 1994).

Compared to dry-rolling, steam-flaking of sorghum grain improves lactation performance in dairy cows (Moore et al., 1992; Poore et al., 1993; Simas et al. 1992; Theurer et al., 1991; Chen et al., 1994), mainly because of increased ruminal (Oliveira et al., 1992; Poore et al. 1993; Chen, 1994) and total digestion of starch (Oliveira et al., 1993; Poore et al., 1993; Simas et al., 1992; Theurer et al., 1991; Chen et al., 1994). In a review of five studies with lactating cows at the University of Arizona showed (Theurer, 1992) that feeding 35 to 43% of diet DM fed as steam-flaked sorghum grain (SFS) increased milk yield 10%, and milk protein yield 15% when compared with dry-rolled sorghum (DRS). In a study to determine interaction between supplementation of fat and processing of sorghum, in immediately postpartum cows, Simas et al. (1995) demonstrated that milk protein percentages were decreased by addition of Ca-LCFA to a dry-rolled sorghum diet (2.93 vs. 2.79%), but not when Ca-LCFA was fed with steam flaked sorghum (3.00 vs. 2.99%). However, DMI was decreased by fat supplementation.

The objective of this study was to determine interactions between three fat sources (one saturated, one unsaturated, and one ruminaly inert) supplemented at 2.5% of DM to the diet and ruminal starch availability (altered by processing sorghum grain) on lactational performance and nutrient digestibilities of high producing dairy cows.

MATERIAL AND METHODS

Holstein cows (48) averaging 81 DIM were fed the normal herd diet (containing 38% alfalfa hay, 12% ammoniated whole cottonseed, 4% cottonseed hulls, and 46% concentrate mix) for a 14 d pretreatment period. Based on milk yield during pretreatment, DIM, and lactation number, cows were assigned to 8 outcome groups and allotted randomly to one of six diets in a 2X3 factorial arrangement of treatments for 64 d. One treatment factor was the sorghum grain processing, dry-rolled (570 g/l) vs. steam-flaked (360 g/l); and the other was source of added fat, cottonseed oil (CO), PFA, or tallow (TL). Diets (Table 13) were: 1) DRS + 2.5% CO (DC); 2) SFS + 2.5% CO (SC); 3) DRS + 2.5% PFA (DP); 4) SFS + 2.5% PFA (SP); 5) DRS + 2.5% TL (DT); 6) SFS + 2.5% TL (ST) .

Cows were housed in pens of 8 each randomly distributed across treatments, offered diets once daily, and milked at 0800, 1600, and 2400 h. Amounts of TMR offered to individual cows were adjusted daily for 10% orts as measured with Calan gates (American Calan Inc., Northwood, NH). Cows were weighed after the 1600 h milking for 2 consecutive days at the beginning and end of treatment. Weekly samples of TMR were composited by treatment for nutrient analyses.

From d 48 to 62 of treatment, TMR were mixed with .1% Cr_2O_3 as an indigestible marker to measure nutrient digestibilities. The Cr_2O_3 (1.5 kg) was first mixed with concentrate (22.5 kg) using a cement mixer, and the mixture then was blended into the TMR (1476 kg) to obtain .1% Cr_2O_3 in the TMR. From day 58 to 62 of treatment, TMR were sampled once daily, and orts were totally collected from each cow. Grab samples of feces were taken twice daily immediately after milking at 0800 and 1600 h. Composites of TMR, orts and feces from the 5 d collection were sub-sampled and nutrient digestibilities were determined from the ratios of Cr concentrations in diets consumed to those in feces.

Samples of TMR, orts, and feces were dried in a forced-air oven at 50 °C for 48 h. Samples were then ground in a cyclone mill (Udy Co., Fort Collins, CO) to pass a 1 mm screen and analyzed for DM (100 °C for 24 h), OM (550 °C for 10 h), CP by AOAC (1990) using a digester (Tectator®; Hogans, Sweden) and N autoanalyzer (Bran and Luebbe, Analyzing Technologies, Elmsford, NY), and ADF and NDF according to the method of Robertson and Van Soest (1981). Long Chain FA were determined according to the method described by Sukhija and Palmquist (1988) using GLC (Model 5890, equipped with a flame ionization detector and auto injector model 7673 A; Hewlett-Pakard, Palo Alto, CA). Starch was analyzed as described by Poore et al., (1991) and Cr according to of Fenton and Fenton (1979).
Milk samples were collected weekly from three consecutive milkings from the initial week of pretreatment to the end of treatment, and daily composites were analyzed at the DHI laboratory (Phoenix, AZ) for fat, protein, lactose, and total solids by infrared procedures; SNF was calculated by

difference between total solids and fat.

Pretreatment data were used for covariate adjustment of DMI, milk yield and composition. Then data were analyzed by the GLM procedure of SAS (1985) using the following statistical model:

$$Y_{ijkl} = M + B_i + G_j + F_k + GF_{jk} + Cov_l + E_{ijkl}$$

where

M = overall mean

B_i = blocking effect

G_j = grain processing effect

F_k = fat source effect

GF_{jk} = interaction between G_j and F_k

Cov_l = covariate effect

E_{ijkl} = random error

Digestibilities were analyzed similarly, but without covariate adjustment of means.

RESULTS AND DISCUSSION

Addition of the fat supplements at 2.5% of diet DM to diets containing 7% whole cottonseed resulted in a mean FA content of 5.5% (Table 14). Individual FA in diets reflected those predominant in the different fat sources with PFA highest in palmitic, and stearic, TL diets highest in oleic and CO diets highest in linoleic. Values for NE_L were calculated according to the NRC (1989); however, because no NE_L estimate was available for SFS, the NE_L for DRS was used. Concentrations of all nutrients were equal to or exceeded recommendations (NRC, 1989).

Intake of DM was not affected by the processing of sorghum grain. Other studies have shown that flaking increased (Chen et al., 1994; Simas et al., 1992) or decreased (Moore et al., 1992; Oliveira et al., 1993; Poore et al., 1993; Theurer et al., 1991; Santos et al., 1993 and 1994) DMI compared to rolling. The reason for the inconsistent effect of processing on DMI is unclear, but may be related to stage of lactation, body condition, milk yield, ambient temperature or other cow conditions.

The only fat supplement to decrease ($P<.01$) DMI was PFA. Chan et al. (1994), Eastridge and Firkins (1991), Wu et al. (1993), and Wu et al. (1994) using cows similar in DIM and levels of fat supplementation, showed no change in DMI with fat addition. Other studies (Andrew et al., 1991; Jerred et al., 1990; and Simas et al., 1995) using cows immediately post partum reported decreased milk yields with added fat which were associated with decreased intakes. Cows in this experiment averaged 81 DIM and were near peak lactation at initiation of treatment and; as indicated by body weight changes did not undergo a net mobilization of fat (Table 15). In early lactation, FA are released from adipose tissue to meet energy demands, which together with FA of dietary origin, might exceed the amount of blood NEFAS that the cow can tolerate without decreasing DMI (Palmquist, 1994). A possible reason that PFA was the only fat source to decrease DMI was because of lower DM digestibilities, which may have limited passage rate.

Steam-flaked sorghum grain did not increase milk yield, which contrasts with results of previous studies (Moore et al., 1992; Oliveira et al., 1993; Poore et al., 1993; Simas et al., 1992; Theurer et al., 1991; Chen et al., 1994) who all showed higher milk yields for steam-flaked compared to dry-rolled sorghum grain. Neither were milk yields significantly different for the different fat sources. Wu et al., (1993) also showed that TL and PFA were of equal value in increasing milk yield when added to alfalfa-based diets at 2.5% of the DM. In another study Wu et al., (1994) demonstrated that a 2.2% addition of either safflower oil (an unsaturated fat source), or PFA increased milk yield similarly when compared to diets with no added fat.

Percentage of milk protein was higher (P<.06) for cows fed SFS compared with DRS. Higher milk protein content of cows fed SFS is consistent with previous studies (Moore et al., 1992; Oliveira et al., 1993; Poore et al., 1993; Simas et al., 1992; Theurer et al., 1992; Chen et al., 1994). Higher ruminal propionate production (Moore et al., 1992; Oliveira et al., 1992; Poore et al.,1993; Chen, 1994) may have contributed to the higher milk protein percentage of milk by sparing AA from gluconeogenesis for milk protein synthesis. Steam-flaking of sorghum also increases microbial CP reaching the small intestine (Oliveira et al., 1995; Poore et al., 1993) making more AA available for absorption and transfer to milk. The study of Wu et al. (1994), which showed higher milk protein percentages from ruminal infusion of glucose than from duodenal infusion of propionate, favors the latter hypothesis. The reason that efficiency of milk protein synthesis per unit of dietary CP was not higher for SFS then DRS is probably because CP content of diets (19.5%) was in excess of that recommended (NRC, 1989). Milk protein yield was not affected by the main factors, but values were 10% higher for SFS then DRS in cows fed TL and slightly lower for SFS groups receiving CO or PFA.

Percentages of fat, lactose, and SNF of milk were not affected by treatment, there was a trend for diets containing CO to be lower in SNF then those with TL or PFA. Changes in body weight were increased (P<.02) by steam-flaking of sorghum compared with dry-rolling (.30 vs. -.01 kg/d), suggesting that additional energy extracted from SFS compared with DRS because of higher starch digestibility, was converted to body weight and not to additional milk as in other studies (Moore et al., 1992; Oliveira et al., 1993; Poore et al., 1993; Simas et al., 1992; Theurer et al., 1991; Chen et al., 1994). The 290 g/d gained by cows fed SFS compared with DRS is energetically equivalent to approximately 1450 Kcal or 2 kg/d of milk (NRC, 1989).

Compared with rolling, steam-flaking increased (P<0.05) digestibilities of DM, OM, CP, and starch, while ADF and NDF digestibilities were decreased (P<.05). Higher DM and OM digestibilities for steam-flaked then dry-rolled are mostly attributed to greater ruminal starch digestion (Oliveira, 1995; Theurer, 1991). The higher CP digestibilities for steam-flaked compared to dry-rolled sorghum might have been because smaller amounts of starch reached the cecum and colon, resulting in less secretion of endogenous N into the lower digestive tract for synthesis of microbial protein, which is largely excreted in the feces. Oliveira et al., (1995) reported a higher pH in feces of cows fed steam-flaked compared with dry-rolled sorghum grain diets, suggesting less fermentation in the lower digestive tract on steam-flaked diets. Differences in starch digestibilities between the steam-flaked and dry-rolled sorghum diets in the present study (97.6 vs. 88.7%) is in agreement with Chen et al. (1994) (98 vs 91%), but were less than in other studies (Oliveira et al, 1993; Poore et al., 1993; Simas et al., 1992; Theurer et al., 1991), which averaged 96% for steam-flaked and 77% for dry-rolled sorghum. The decrease in digestibilities for ADF and NDF when the sorghum was flaked, might have been because of a decreased ruminal pH (Oliveira et al., 1992; Poore et al., 1993; Chen et al., 1994), which often lowers cellulolytic bacteria activity (Herrera-Saldana, 1990). Prilled tallow fatty acids decreased DM, OM, and CP digestibilities compared to the other fat sources. Wu et al. (1993) reported no differences in digestibilities of any nutrient when cows were PFA or TL, or when safflower oil and PFA were added to SFS diets (Wu et al., 1994). Digestibilities of FA were not different for the different fat sources, probably because of relatively low level of fat supplementation. These results agree with Wu et al. (1993) who showed no difference in FA digestibilities of TL and PFA when at 2.5% of the diet DM, or with Wu et al. (1994) who showed no differences in digestibilities of FA between safflower oil and PFA at 2.5% diet DM.

The NE_L of diets was estimated from maintenance requirements, BW change, daily FCM yield, and DMI, using established relationships (NRC, 1989). Dietary differences between DRS and SFS were totally attributed to differences in between the grains. For a base reference, the NE_L of DRS was assumed to be 1.84 Mcal/kg, (NRC, 1989). Principally because of higher body weight gains, estimated NE_L for SFS calculated to be 2.25 Mcal/kg, or 22.6% higher than for DRS. The higher NE_L for steam-flaked sorghum than dry-rolled sorghum is similar to the increase estimated in previous studies (Theurer et al., 1991; Chen et al., 1994).

CONCLUSIONS

Contrary to previous studies, steam-flaking of sorghum grain did not improve lactational performance in cows fed diets supplemented with 2.5% of their DM as fat. However, milk protein content and starch digestibilities were increased by steam-flaking. The greater increase in body weights of cows fed steam-flaked compared with dry rolled sorghum grain resulted in a 22.6% increase in estimated NE_L. The different fat sources one unsaturated, one saturated and one ruminaly inert, appeared to have the same nutritional value for milk production and affected milk composition , similarly.

Table 13. Ingredient and nutrient composition of diet DM

Ingredients	%
Alfalfa hay	38.3
Cottonseed hulls	4.9
Whole cottonseed	6.9
Sorghum grain[1]	34.1
Soybean meal	9.7
Dried molasses	1.5
Buffer[2]	1.4
Mineral and vit mix[3]	1.5
Fat[4]	2.5
Nutrient	
OM	91.9
CP	19.5
ADF	21.5
NDF	28.3
Starch	25.4
NE_L[5] (Mcal/kg)	1.67

[1] Steam flaked or dry rolled
[2] 1.1% $NaHCO_3$, .4% MgO
[3] Containing calcium carbonate, .50%; biophosphate, .58%; trace mineral salts, .26%; and vitamins A, D and E, .16% (calculated to furnish 50,000 IU of vitamin A, 5,000 IU of vitamin D, and 250 mg of vitamin E/d per cow).
[4] Cotton seed oil, tallow or prilled tallow fatty acids
[5] Estimated from NRC (1989).

Table 14. Fatty acid (methyl esters) content and composition of diets (SM basis)

	Diets[1]					
	DRS			SFS		
Fatty acid	TL	CO	PFA	TL	CO	PFA
Content, % of DM	5.5	5.4	5.6	5.4	5.5	5.6
	(g/100 g of methyl esters)					
C14:0	1.4	0.4	1.1	1.4	0.4	1.1
C16:0	23.1	17.5	28.1	23.2	17.8	28.0
C18:0	7.7	3.6	16.7	7.3	3.0	16.2
C18:1	24.2	16.2	13.9	23.1	16.2	14.0
C18:2	28.8	52.3	27.3	30.0	53.9	28.2
C18:3	3.8	3.8	4.3	3.9	3.5	3.7
Other	11.0	6.2	8.6	11.1	5.2	8.8

[1] Dietary treatments: DRS = dry-rolled sorghum, SFS = steam-flaked sorghum; TL = 2.5% tallow, CO = 2.5% cottonseed oil, PFA = 2.5% prilled tallow fatty acids.

Table 15. Effect of sorghum grain processing and fat source on lactation performance of dairy cows.

	Diets[1]							P<[2]		
	DRS			SFS						
Item	TL	CO	PFA	TL	CO	PFA	SEM	G	F	G*F
DMI, kg/d	27.0	26.1	23.1	26.8	24.8	24.3	1.5	.96	.12	.73
Intake, % BW	4.43	4.26	3.96	4.42	3.85	3.82	.28	.42	.16	.79
Milk, kg/d	40.8	42.6	41.6	43.1	39.8	39.4	1.3	.38	.55	.11
3.5% FCM	37.5	39.6	37.6	40.1	36.1	35.1	1.4	.32	.25	.11
FCM/DMI	1.35	1.42	1.58	1.37	1.38	1.42	.11	.54	.46	.71
Milk fat, %	3.02	3.09	2.91	2.95	2.88	2.97	.09	.37	.88	.36
kg/d	1.18	1.30	1.20	1.29	1.15	1.15	.06	.48	.53	.08
Milk protein,%	3.11	3.04	3.07	3.14	3.13	3.18	.05	.06	.65	.68
kg/d	1.23	1.29	1.27	1.37	1.24	1.23	.04	.59	.60	.07
g/kg CPint	216	244	275	234	255	254	19	.85	.14	.57
Milk lactose,%	4.79	4.85	4.88	4.86	4.80	4.92	.05	.67	.29	.45
Milk SNF, %	8.50	8.47	8.50	8.65	8.30	8.69	.11	.53	.11	.21
Initial BW,kg	668.4	676.5	645.3	658.2	683.3	663.2	20.8	.78	.46	.79
BW change,kg/d	.02	-.09	.03	.16	.25	.50	.16	.02	.45	.61

[1] Dietary treatments: DRS = dry-rolled sorghum, SFS = steam-flaked sorghum; TL = 2.5% tallow, CO = 2.5% cottonseed oil, PFA = 2.5% prilled tallow fatty acids.
[2] G = sorghum grain processing effect; F = fat source effect; G*F = interaction between G and F.

Table 16. Sorghum grain processing and fat supplementation effects on nutrient digestibilities

	Diets[1]							P<[2]		
	DRS			SFS						
Item	TL	CO	PFA	TL	CO	PFA	SEM	G	F	G*F
DM	66.5	65.5	61.0	67.5	67.9	65.0	1.4	.03	.01	.55
OM	67.7	66.3	62.2	68.8	69.9	66.6	1.4	.01	.01	.48
CP	67.6	63.6	62.3	70.4	68.5	68.2	1.3	.01	.02	.49
Starch	86.2	90.9	88.9	97.5	97.8	97.5	1.1	.01	.07	.14
ADF	52.5	43.2	42.4	35.2	39.4	33.0	3.5	.01	.22	.16
NDF	50.0	46.8	37.0	37.5	42.4	36.2	4.0	.08	.10	.34
FA	70.7	71.1	71.3	74.6	71.6	71.7	2.4	.41	.82	.70

[1] Dietary treatments: DRS = dry-rolled sorghum, SFS = steam-flaked sorghum; TL = 2.5% tallow, CO = 2.5% cottonseed oil, PFA = 2.5% prilled tallow fatty acids.

[2] G = sorghum grain processing effect; F = fat source effect; G*F = interaction between G and F.

SUMMARY AND CONCLUSIONS

Three experiments were conducted to determine the effect of sorghum grain processing and fat supplementation on lactational performance and nutrient utilization in dairy cows. Major findings from these studies were: 1) Steam flaking of sorghum grain increased both ruminal and total tract digestibilities of starch, and increased VFA production when fat was not supplemented; 2) Steam-flaked compared with dry-rolled sorghum improved milk and milk protein yields; 3) Milk protein content was increased by steam-flaked sorghum; 4) Efficiency of conversion of dietary protein to milk protein was increased by flaking of sorghum when dietary CP was not excessive; 5)When steam-flaking did not improve milk yield, body weight gains were increased with a concomitant increase in NE_L of sorghum grain of about 22.6% when compared with dry-rolled sorghum (2.25 vs 1.84 Mcal/kg); 6) Fat supplementation of ruminally inert fat at 2.5% of DM in diets containing 7-10% whole cottonseed increased milk and milk protein yields when compared to unsupplemented diets; 7) At 5% of diet DM cows did not respond to supplementation of ruminally inert fat; 8) Cows responded similarly to fat sources which varied widely in degree of saturation (cottonseed oil, tallow, and prilled hydrogenated fatty acids) added at 2.5% of diet DM; 9) Cows producing extremely high levels of milk responded positively to both steam-flaking of sorghum and supplementation of fat, with the effects being additive at 2.5% but not at 5% added fat.

The increased milk and milk protein yield resulting from feeding more rumen degradable starch may be related to greater energy absorption from VFA and/or better utilization of dietary protein (because of increased microbial protein synthesis in the rumen; or reduced oxidation of AA or increased propionate absorption, which would spare AA from gluconeogenesis in the liver). Increased VFA concentration with steam-flaked sorghum was demonstrated in our first trial and by other workers (Moore et al., 1989; Theurer et al., 1991; Chen et al., 1994). In contrast with previous studies (Poore et al., 1993; Oliveira et al., 1995, Chen et al., 1994) and our study did not show that steam-flaking of sorghum increased microbial protein flow to the duodenum. The increased propionate and failure to increase microbial protein in our study agrees the findings or Wu et al. (1994), who showed that increased propionate availability did not result in increased milk protein content. However, ruminal infusion of glucose tended to increase microbial protein synthesis, and did increase milk protein content.

The NE_L calculations for SFS (which averaged 22.6% higher than for DRS) were based on maintenance needs, milk energy secretion and body weight change of cows. In the second lactation study where milk yield was not increased by flaking of sorghum, the higher body weight gains might be explained by an increased release of glucose from the splanchnic area this resulting from higher arterial insulin concentrations and greater lipid deposition in the body.

Fat supplementation at 2.5% of DM in diets containing 7-10% whole cottonseed increased lactational performance of cows at peak or near peak production, whereas 5% fat was ineffective. The additivity of supplemental fat and steam flaked sorghum at very high producing levels has important commercial implications.

Different fat sources (cottonseed oil, tallow, prilled hydrogenated fatty acids) fed at 2.5% of DM in diets containing 7% whole cottonseed appeared to have similar nutritional value. These findings agree with Grummer et al. (1994), who recommended that a first increment of fat supplementation should be from whole oilseeds because of economics and their furnishing of other nutrients; and that a second increment from a natural or inert fat source, but not to exceed 5-6% fat supplementation.

In contrast to the review of Wu and Huber (1994) milk protein percentages were not depressed by fat added at 2.5% diet DM. This difference may have been because of the type of diets used (34 to 38% alfalfa hay and 33 to 40% sorghum grain) or because of the processing of the sorghum, which in one study significantly increased the proportion of dietary protein secreted as milk protein. Most of the studies reviewed by Wu and Huber (1994) were with corn and alfalfa silage diets and often contained higher than 2.5% added fat.

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