INFLUENCE OF SORGHUM GRAIN HYBRID AND CORN ON SITE AND EXTENT OF DIGESTION IN BEEF STEERS

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IN BEEF STEERS

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CHAPTER I

INTRODUCTION

Corn and sorghum grain are the most often utilized cereal grains in feedlot diets. Corn is the preferred grain, but sorghum grain is used extensively in some regions, because sorghum grain can be grown successfully under a wider range of dryland and irrigation conditions than corn. However, sorghum grain is more variable in quality (protein and starch content) than corn, partially because of environmental influences (Wall and Ross, 1970), but also because of varietal and hybrid differences (Miller et al., 1962). Consequently, predictability of growth rates and efficiency of feed utilization may be reduced when NRC (1984) energy values for sorghum grain are used. Variation in cattle performance associated with different sorghum grain hybrids or varieties (McCollough et al., 1972; Maxson et al., 1973) may partially be due to differences in digestibility (McCollough and Brent, 1972).

Corn and sorghum grain are very similar in composition (Rooney and Pflugfelder, 1986), yet corn has generally supported greater rates of gain than sorghum grain (McCollough et al., 1972). Attempts to identify sorghum grain endosperm types with improved digestive qualities have indicated grain with floury (Miller et al., 1972) or waxy (Hibberd et al., 1982a,b) endosperm are superior to normal endosperm. Unfortunately, grains with floury endosperm are of limited commercial usefulness because of low density and test weight (Sullins

and Rooney, 1974), while grain with waxy endosperm has been slow in development because of reduced yield potential (Rooney and Pflugfelder, 1986). Recently, Brethour (1987) compared sorghum grain with a pure yellow endosperm to corn, noting no difference in rate and efficiency of gain in beef steers. However, Goldy et al. (1987) reported no advantage in growth rate or efficiency of gain in steers fed homozygous yellow endosperm sorghum hybrid compared to heterozygous yellow endosperm sorghum hybrids differing in seed coat color. Moreover, corn resulted in a statistically similar rate and efficiency of gain, but numerically gains with corn were 8% greater than yellow and 11% greater than hetero-yellow endosperm sorghum grain hybrids.

Sorghum grain breeders have suggested that hybrids of differing genetic backgrounds should differ with respect to digestibility of starch and protein. Additionally, currently available sorghum grain hybrids have not been compared to corn. Because sorghum grain varieties differ in site and extent of digestion (Streeter et al., 1989a) one may expect differences among hybrids. Endosperm characteristics of sorghum hybrids may alter ruminal fermentation and intestinal digestion; hence, altering the efficiency of energy utilization (Black, 1971). The extent to which different sorghum grain hybrids compare to corn and each other and alter site and extent of digestion is virtually unknown. The objective of these studies was to quantify the differences between corn and currently available sorghum grain hybrids in chemical composition, in the extent of starch digestion in the rumen and in the small and large intestines and in the extent of grain protein escape to the small intestine in beef cattle. To accomplish our objectives, three experiments were conducted. The

first compared four sorghum grain hybrids, representing a homozygous yellow endosperm grain, two heterozygous yellow endosperm grains differing in seed coat color and a homozygous white endosperm grain, to corn to quantify differences in site and extent of starch and protein digestion in beef steers. The second trial compared six genetically unique sorghum grain hybrids, representing two homozygous yellow endosperm grains, two heterozygous yellow endosperm grains with a red seed coat and two heterozygous yellow endosperm grains with a white seed coat to identify differences in site and extent of starch and protein digestion in beef steers. The third experiment concentrated on physical and chemical differences between eight divergent sorghum grain hybrids and corn.

CHAPTER II

LITERATURE REVIEW

Factors Affecting Corn and Sorghum Grain Digestibility

Corn and sorghum grain are very similar in chemical composition (Rooney and Pflugfelder, 1986) yet, corn has generally supported greater rates of gain than sorghum grain (McCollough et al., 1972). Recently, Brethour (1987) compared sorghum grain with a homozygous yellow endosperm to corn noting no difference in rate or efficiency of gain in beef steers. Goldy et al. (1987) observed no advantage in growth rate or efficiency for steers fed homozygous yellow endosperm compared to heterozygous yellow endosperm sorghum grain hybrids. Moreover, corn resulted in a similar rate and efficiency of gain. Numerically, however, gains with corn were 8% greater than pure yellow and 11% greater than hetero-yellow endosperm sorghum grain hybrids.

McCollough and Brent (1972) and Schake et al. (1976) suggest that sorghum grain is 5 to 10% less digestible than corn. Barley may also have greater feeding value for cattle than sorghum grain (Saba et al., 1964). Spicer et al. (1986) concluded that corn and barley had slightly greater total tract starch digestibility than sorghum grain. Ruminal starch digestion was greater for corn (83.7%) and barley (87.7%) than for sorghum grain (75.2%) of unknown background. Total tract N digestibility was much greater for corn and barley compared to

sorghum grain. Waldo (1973) noted slightly greater ruminal starch digestibility for corn than sorghum starch. Less variation in ruminal corn starch digestion was noted than for ruminal sorghum grain starch digestion. Sorghum varieties, however, do exist that have a higher digestibility than corn (Samford et al., 1970; Miller et al., 1972).

Sorghum grain usually has a much greater proportion of endosperm as peripheral cells than corn (Rooney and Miller, 1982). Because sorghum grain peripheral endosperm cells have a high protein content and resist both physical and enzymatic degradation (Rooney and Pflugfelder, 1986), one would expect sorghum grains with more peripheral endosperm to be less digestible and sorghum to be less digestible than corn. Tanksley and Knabe (1984) have found the protein of yellow endosperm sorghum to be 5% less digestible than corn protein in swine. Rooney and Riggs (1971) and Wagner (1984) have postulated a relationship between starch recovery from wet milling and ruminal starch digestibility. Perhaps a similar relationship exists within the small intestine, and to a lesser extent, the large intestine. Low starch yields from wet milling of sorghum grain may be caused by the density of the peripheral endosperm layer (Watson et al., 1955). Wagner (1984) reported differences in wet milling properties among sorghum grain varieties related to the proportion of peripheral endosperm. The proteins in corneous endosperm are composed of protein bodies (kafirin) and a continuous protein matrix (glutelin). Corneous endosperm (measured by hardness) in sorghum grain is the result of protein content, the continuity of the peripheral protein matrix (Rooney and Miller, 1982) and hybrid (Hoseney, et al., 1974). Differences among sorghum hybrids ruminal, pre-cecal and intestinal

starch digestibility are likely the result of differences in the amount of peripheral endosperm and continuity of protein matrix as indirectly indicated by geometric mean diameter (GMD) and particle size distribution. Additionally, intermolecular cross links are found in some sorghum prolamine protein fractions that decrease the extractability, but more importantly, digestibility of both the protein and starch granules embedded in matrix protein. Differences between corn and sorghum hybrid starch and protein digestibility may also be related to protein matrix in the peripheral endosperm. While the composition of corn and sorghum endosperm (protein and starch) is similar, protein of sorghum is more difficult to extract using classical solvent extraction techniques than corn and other cereals (Wall and Paulis, 1978). Additionally, separation of starch and protein by wet milling is more difficult in sorghum than corn with the resulting starch generally contains more protein than commercial corn starch (Rooney and Pflugfelder, 1986).

McCollough and Brent (1972) have shown that endosperm type is related to digestibility of sorghum grain. Within eight sorghum hybrids tested, grains with white endosperm tended to have lower digestibilities than those with yellow endosperm. One bird resistant hybrid included in the study had greatly reduced crude protein and dry matter digestibilities. Rooney and Pflugfelder (1986), in a recent review, noted that hetero-yellow sorghum grain was of higher feeding value than sorghum grain with a non-yellow endosperm. Hibberd et al. (1985) and Streeter et al. (1989b), however, were unable to determine differences in total tract starch digestibility among sorghum grain hybrids and varieties, respectively. But ruminal starch digestion was

greater for a hetero-yellow hybrid than other non-yellow endosperm hybrids in the study reported by Hibberd et al. (1985). Differences between corn and sorghum grain types may reflect differences in the proportion and continuity of peripheral endosperm and protein matrix (Rooney and Pflugfelder, 1986). Miller et al. (1972) found the percent floury endosperm influenced sorghum grain digestibility. Sorghum varieties with greater than 75% floury endosperm had higher nylon bag dry matter digestibility than those with less than 40% floury endosperm. Grains with a brown (bird resistant) or a purple seed coat tended to have lower digestibilities regardless of floury endosperm content. However, grain with floury endosperm generally has a low density and test weight limiting its commercial usefulness (Sullins and Rooney, 1974). Sorghum grain digestibility is decreased as berries become harder (Samford et al., 1970). Berries become harder as the proportion of soft floury endosperm declines. Therefore, factors related to hardness indirectly estimate the ratio of peripheral to floury endosperm. Decreasing moisture, berry size and soil fertility may increase berry hardness. The primary seed characteristic related to seed hardness; however, is endosperm type. Berries with floury endosperm are softer than berries with normal or waxy endosperm (Sullins and Rooney, 1974).

Sorghum varieties with waxy endosperm have higher in vitro dry matter disappearance (IVDMD; Hibberd et al., 1982a,b; Streeter et al., 1989a) and in vivo starch digestibility than varieties with normal endosperm (Nishimutta et al., 1969; Streeter et al., 1989b). Waxy starch may be more available due to the branched nature of amylopectin (French, 1973), or increased starch granule accessibility due to

greater solubility of peripheral endosperm matrix protein, less amorphous protein matrix and less peripheral endosperm (Sullins and Rooney, 1974; Lichtenwalner et al., 1978). Seckinger and Wolf (1973) suggest protein encapsulation of starch granules limits sorghum starch digestibility. Higher protein sorghum grains are also given lower energy values by the beef cattle NRC (1984). The protein matrix surrounding the starch granule is extremely dense and insoluble in the peripheral endosperm of sorghum grain. Information is currently not available on more recent sorghum grain hybrids concerning the relationship of protein and energy. NRC (1984) energy values for sorghum grains are, therefore, in need of investigation.

Bird resistant (BR) sorghum varieties contain condensed tannins that give the grain an astringent taste reducing palatability and digestibility (Saba et al., 1972). Muindi et al.(1981) treated BR sorghum high in tannin with magadi soda to remove condensed tannins (40 to 57%) and noted increased in vitro OM, starch and CP digestion. However, soda treatment did not result in levels equal to low tannin non-BR sorghum grain and low tannin grains were not influenced by soda treatment. This indicates that factors other than tannin influence digestion in vitro. Studies using rats reported by Muindi and Thomke (1981) are in agreement with in vitro experiments. On the other hand, BR types with waxy endosperm have greater IVDMD than BR types with normal endosperm (Hibberd et al., 1982a,b). Other factors associated with the BR characteristic may influence OM and CP digestion and need further investigation.

Inheritance of Yellow Endosperm in Sorghum Grain Hybrids

Sorghum grain may have two different endosperm colors due to the presents or absents of carotenoid pigments. Grain with a yellow endosperm may be more digestible than that with a white endosperm. The inheritance of yellow endosperm is not clearly understood but is thought to involve four alleles. Presumably, heterozygous yellow hybrids may have either a third or two thirds yellow endosperm. Differences in the digestibility of heterozygous yellow grains partially may result from varying proportions of yellow endosperm. The seed coat color of heterozygous yellow endosperm grains is not involved with the proportion of yellow endosperm. Hence, cream hybrids (heterozygous yellow endosperm, white seed coat) do not contain a greater proportion of yellow endosperm than hetero-yellow (heterozygous yellow endosperm, red seed coat) hybrids, even though the cream grains physically appear to be more like a pure yellow hybrid (homozygous yellow endosperm, yellow seed coat) than a hetero-yellow.

Factors Affecting Site and Extent of Starch and Protein Digestion

The need for more efficient production has forced the beef cattle industry to shift from forage to concentrate feeding. Grain processing, feeding regimes and feed additives have been developed to further enhance the efficiency of production by increasing the availability and utilization of the cereal grain portion of rations. A great deal of research has been conducted to determine the effect of altering the site of cereal grain starch and protein digestion on total tract utilization. Interest in the effect of starch digestion in the

small intestine on animal performance has been great. Theoretical calculations with concentrates fed to non-ruminant lambs demonstrate the potential for more efficient production due to reduced energy loss from methane (Black, 1971).

The small intestine has a relatively large capacity to digest starch; however, a ceiling has been suggested. Waldo (1973) suggested an upper limit of 7.7 g of starch or 8.6 g glucose per kilogram of metabolic body weight (kg body $wt^{\cdot 75}$). Escape of starch from ruminal fermentation may play an important role in meeting the glucose requirements of high producing animals (Armstrong and Smithard, 1979). Greater glucose absorption from the small intestine should allow propionic acid and glucogenic amino acids produced in the rumen to be utilized for functions other than gluconeogenesis (Sutton, 1971). However, Orskov (1986) suggests that exogenous glucose metabolism by the liver may be a possible constraint limiting dietary starch utilization in ruminants. Net portal glucose flux has been reported to be to the gut with high concentrate diets that should have resulted in substantial glucose absorption from the small intestine (Huntington et al., 1981; Huntington, 1984). Additionally, glucose and starch infusion into the small intestine by Huntington and Reynolds (1985) resulted in only 65% of infused glucose and 35% of infused starch being recovered in the portal blood. Net flux of glucose to the gut with high concentrate diets may reflect gut utilization; however, lymph flow has not been monitored. Glucose may be metabolized to lipid within the intestine. Rust (1983) infused glucose into the abomasum or provided an equal amount of glucose in the diet in a 165-d lamb feeding study. Empty body energy retention for lambs fed glucose was only 52% of that

observed with abomasal infusion. However, 87% of the increased energy retention could be accounted for by lipid deposition around the intestines and in the omentum.

The level of starch intake and rate of passage play an important role in determining the amount of starch reaching both the small and large intestines. Karr et al. (1966) reported increasing starch intake, achieved by reducing alfalfa levels fed to steers from 1002 to 2684 g/d, increased starch recovery at the abomasum (357 to 982 g/d). Similar increases in starch reaching the ileum (26 to 358 g/day) and feces (12 to 62 g/day) were noted. DeGregorio et al. (1982) found a similar increase in starch reaching the small and large intestines of lambs as corn level in the diet increased with a constant DM intake. Differences in rates of passage of particles from the rumen have been suggested as the cause of increasing starch escape with higher starch intakes by Orskov et al. (1969); however, Weller and Gray (1953) have suggested that as much as 80% of dietary starch may move with the fluid phase.

Starch escape from the rumen and starch fermentation in the large intestine may substantially change the N and essential amino acid status of an animal. Increasing starch flow to the small intestine reduces the amount of energy available for microbial protein synthesis (Orskov, 1977). Decreased microbial protein synthesis, caused by reduced energy availability, could result in less protein flowing to the abomasum, (Orskov et al., 1969; Sutton, 1971; Waldo, 1973). More importantly, reduced microbial protein synthesis could decrease the supply of essential amino acids presented to the small intestine for absorption (Black, 1971). Zinn and Owens (1983b) reported increasing

feed intake of a 63% dry rolled corn diet resulted in an increased flow of nitrogen (N), non-NH_3 nitrogen (NAN), microbial N and feed N to the small intestine. Perhaps increasing feed intake results in enhanced efficiency of microbial protein production (Zinn and Owens, 1982b). Interestingly, in the same study ruminal starch digestion increased with feed intake (79.6 to 91.0%).

Fermentation of starch in the large intestine may result in the excretion of microbial protein in the feces (Orskov et al., 1969; Armstrong and Smithard, 1979). Orskov (1982) reported total N excreted in the feces to be greater than that passing the terminal ileum when starch was infused into and fermented within the large intestine. The most efficient use of starch and protein by the ruminant occurs when degradation occurs prior to the cecum.

Factors Affecting Ruminal Starch and Protein Fermentation

Level of feed intake, starch intake and method of processing are factors that alter ruminal starch and protein digestion. Dietary factors probably exert their influence by altering the ruminal environment (pH, ammonia concentration, particulate passage rate and liquid dilution rate). The level of feed intake and source of roughage may cloud many estimates of ruminal starch digestion. Decreased ruminal starch digestion was noted by Galyean et al. (1979) as intake was increased from 1 (94.5%) to 2 (89.6%) times maintenance. Roughage was supplied by cottonseed hulls and dehydrated alfalfa (50:50). Liquid dilution rate and outflow rate from the rumen increased with DM intake. Weller and Gray (1953) suggest that 85 to 93% of ingested

starch resides in the liquid phase of the rumen. Therefore, liquid dilution rate should be inversely related to ruminal starch digestibility. Zinn and Owens (1980) noted a decrease in ruminal starch digestion as intake was increased from 1.5 (79.1%) to 2.0 (62.3%) % of body weight. However, starch digestion in the rumen increased as DM intake increased from 1.2 (79.6%) to 2.1 (91.0%) percent of body weight in studies conducted by Zinn and Owens (1983a). Cottonseed hulls were utilized as the sole roughage source and may not have stimulated rumination to the extent of a more course (larger particle size) roughage source. Less rumination would reduce salivary flow; thereby, lowering ruminal pH and possibly increasing starch digestion in the rumen (Goetsch et al., 1983). However, one would expect greater starch digestion to occur when ruminal buffering capacity is maximized by greater salivary flow. Zinn and Owens (1982a) reported ruminal N digestion decreased with greater DM intake. A similar depression in ruminal protein digestion was reported by Zinn and Owens (1980). Feed N digestibility in the rumen may be reduced due to more rapid liquid dilution rate or particulate passage rate as DM intake is increased. Changes in ruminal pH, resulting from variation in salivary flow, may also alter feed protein solubility and digestibility within the rumen. Likewise, changes in particulate passage rate and (or) ruminal pH may adversely affect ruminal microbes ability to degrade feed N. Alterations in pH may increase the time required for microbes to attach to feed particles (lag time), while greater particulate passage rate would reduce time allowed for ruminal digestion.

Processing of cereal grains increases ruminal starch digestion more than other factors. Galyean et al. (1976) compared starch digestion in steers fed corn rations processed by dry rolling, steam flaking, high moisture harvesting followed by grinding (HMG) and high moisture harvesting with propionic acid treatment (HMA) prior to ensiling. Ground high moisture harvested corn had the greatest ruminal starch digestibility (89.3%) followed by steam flaked (82.9%), dry rolled (77.8%) and HMA (62.8%). McNeill et al. (1971) compared dry rolled (42.2%), steam flaked (82.3%), reconstituted (66.2%) and micronized (43.4%) sorghum grain with steam flaking increasing ruminal starch digestion more than other processing techniques. Hibberd et al. (1985) reported greater ruminal starch digestion with reconstituted sorghum grain compared to dry rolled grain. Enhanced ruminal starch digestibility for high moisture processing may result from extensive solubilization of peripheral endosperm matrix protein or hydration of the protein matrix resulting in smaller particles less affected by encapsulation of starch within the protein component. Steam flaking probably increases ruminal starch digestion by gelatinization of starch granules (Galyean et al., 1976).

Several researchers have investigated the effects of level of roughage on starch digestion. Karr et al. (1966) reported starch digestion in the rumen decreased by 15.2% as the level of ground corn increased in the diet. Other researchers, using different roughage sources, have reported no or small depressions in starch digestion as the level of roughage was reduced in the diet (Cole et al., 1976a; Russell et al., 1981). Zinn and Owens (1980), utilized prairie hay as a roughage source and noted an 18% increase in ruminal starch

digestibility as the roughage level was increased from 20 to 40% of the diet DM. Increasing roughage levels should cause a greater ruminal liquid dilution rate. Small particles could be carried out of the rumen with ruminal liquid (Weller and Gray, 1953; Van Soest, 1982). Association of starch particles with the solid or liquid phase of the rumen may depend on roughage source and grain particle size. Roughages that cause more rumination and salivary flow to the rumen resulting in greater ruminal pH may decrease ruminal starch digestion. Goetsch et al. (1983) infused base intraruminally, noting increased fiber digestion and decreased starch digestion in the rumen as ruminal pH was raised from 5.8 to 6.2. Additionally increased salivary flow may increase liquid dilution rate and the rate starch flows out of the rumen (Froetschel et al., 1989). Limited work has been conducted to evaluate the effects of different roughage sources on ruminal starch digestion. Goetsch et al. (1984) investigated the effect of roughage sources for dry rolled sorghum diets. Starch digestion in the rumen tended to be higher when cottonseed hulls were the roughage or when no roughage was provided (100% sorghum). Particulate passage rate was negatively correlated (r= -.55) to ruminal starch digestion and was greatest for alfalfa (4.1%/h). Liquid dilution rate (%/h) was also greatest with alfalfa (8.0). Goetsch and Owens (1984) compared 7% cottonseed hulls with 14 and 21% whole shelled corn in dry rolled sorghum grain diets fed to steers. Ruminal starch digestion was greatest for rations containing 21% whole shelled corn (79.6%) followed by 7% cottonseed hulls (75.4%) and 14% whole shelled corn (70.0%). Further study is needed to determine the interactions of roughage source, starch source and ruminal parameters. Perhaps future research

should concentrate on the effects of a single roughage source at a constant level with decreasing roughage particle size.

Sorghum variety greatly influences ruminal digestion. Varietal differences in starch digestion have been indicated in vitro (Hibberd et al., 1982b; Streeter et al., 1989a) and in vivo (Hibberd et al., 1985; Streeter et al., 1989b). Continued research into varietal differences with sorghum may yield information useful in the selection of more digestible varieties.

The protein supply to the rumen is interrelated to the microbes ability to utilize energy. Many of the same factors that affect starch digestion and passage from the rumen also influence ruminal protein degradation and escape. Ammonia, derived from feed protein or NPN, is the main N source used in bacterial protein synthesis. Ruminal ammonia levels can greatly affect ruminal digestion (Mehrez and Orskov 1976). Satter and Slyter (1974) reported a minimum of 5 mg of NH_3-N/dl for maximal microbial N production in forage-based diets. Weakley (1983) suggested higher values may be needed to obtain maximum ruminal OM digestion (5 to 10 mg/dl). Still higher values have been reported in sheep for maximal OM digestion (Mehrez and Orskov, 1976). Much lower ruminal NH_3-N concentrations (1 to 3 mg/dl) are commonly noted with feedlot type diets (high concentrate). Lower ruminal NH_3-N levels may result from rapid utilization of NH_3-N due to readily available energy from starch. Additionally low ruminal NH_3-N concentrations may not be representative of the NH_3-N levels in the micro-environment surrounding grain particles (Czerkawski, 1986). To date, studies have not investigated the effects of increasing ruminal NH_3-N levels on OM digestion or efficiency of microbial protein production in high

concentrate diets. One would expect increased OM digestion with greater NH_3-N availability based on information obtained with forage-based diets.

Ruminal pH has many effects on ruminal digestion, some of which have been previously mentioned. Solubility of protein in the rumen are altered by ruminal pH (Waldo and Goering, 1979). Reduced protein solubility has been suggested to be the main factor limiting protein degradation in the rumen. However, numerous attempts to equate protein solubility in mineral buffers to ruminal protein degradation have met with limited success (Wohlt et al., 1973; Waldo and Goering, 1979). Mahadevan et al. (1980) proposed that solubility by itself does a poor job of explaining ruminal differences; however, protein structural characteristics that may influence solubility appear to play an important role in limiting protein degradation. The source of dietary protein is related to ruminal degradation and escape through differences in solubility, cross linking and structure of the protein (Orskov et al., 1971; Hume, 1974; Hembrey et al., 1975; Arambel and Coon, 1981).

Low ruminal pH (< 6.0) has been shown, in vitro, to reduce microbial protease and deaminase activities (Erfle et al., 1982). Processing of grains may also alter protein solubility through denaturation or pH changes resulting from ensiling. Reduced protein solubility and digestibility is a particular problem at intermediate grain storage moisture levels (22 to 26%) When grain is properly processed, protein utilization may be enhanced due to protein factors such as solubility and hydration (McNeill et al., 1975) and non-protein

factors such as ruminal dilution rate (Potter et al., 1971; Prigge et al., 1978; Aguirre et al., 1984).

Ruminal protein digestion is also influenced by levels of protein and feed intake. Zinn and Owens (1981) observed a 52% increase in ruminal bypass of feed N as feed intake was increased from 1.6 to 2.2% of body weight. Increasing feed intake resulted in a curvilinear increase in ruminal escape of feed N, with the greatest increase occurring between 1.8 and 2.0% of body weight. Greater escape with DM intake supports the use of protein solubility as a measure of ruminal protein digestion, because as DM intake increases, ruminal dilution rate should increase, reducing the time allowed for N digestion (Zinn and Owens, 1983a). Linear responses of N reaching the duodenum to increasing feed intake (Zinn and Owens, 1983a) and protein level (Laughren and Young, 1979) also have been reported.

Roughage level influences N digestion possibly by altering ruminal retention time or pH. Generally ruminal digestion of natural protein is greater when animals are fed a high roughage than fed a high concentrate diet (Zinn and Owens, 1983b). Ganev et al. (1979) reported disappearance of protein from nylon bags suspended in the rumen of sheep to be greater when dried grass was fed compared to whole barley diets. Chyme outflow rate also was greatest when sheep received dried grass and increased with feed intake.

Cole et al. (1976b) suggests increasing roughage level causes greater N recycling to the rumen resulting from greater salivary flow. Extensive N recycling causes greater amounts of N to flow to the duodenum (Nolan et al., 1973). Often total N flow to the duodenum exceeds N intake when high concentrate diets are fed. The rate of

diffusion of endogenous urea into the rumen is the result of the concentration of plasma urea and ruminal ammonia. The rate of ammonia utilization by ruminal microbes is a function of bacterial growth rate and is greatly influenced by ruminal OM digestibility. Clearance of urea to the rumen may be enhanced in both sheep and cattle by the addition of grain to the diet (Kennedy and Milligan, 1980). Grain addition to the diet may increase N diffusion into the rumen because rapid ammonia utilization accompanied by starch fermentation should lower ruminal ammonia levels increasing the concentration gradient between blood plasma and the rumen.

Barry and Manley (1984) have reported increased N recycling associated with depressed ruminal OM digestion caused by tannins in forages. Hibberd et al. (1985) reported N reaching the duodenum exceeded N intake when BR sorghum diets were fed to steers; however, corrected ruminal OM digestion was not depressed. The relationship between depressed OM fermentation associated with high tannin feedstuffs and increased N flow to the duodenum in cattle is in need of investigation. Mehansho et al. (1983) reported that feeding high tannin sorghum grain to rats resulted in a dramatic change in the parotid salivary gland. After 3 d of feeding BR grain to rats, their parotid glands had enlarged three fold, and a group of proline-rich proteins (PRP) in the saliva had increased about 12 fold. Hagerman and Butler (1981) reported that proline concentration was the protein characteristic having the greatest correlation with tannin affinity. The PRP from rat and human saliva contain 25 to 45% proline. Salivary PRP have a very high affinity for condensed tannins and are thought to protect against the anti-nutritional effects of dietary tannin

(Mehansho et al., 1987). When rats are fed high tannin sorghum grain, weight loss is observed for about 3 d followed by an initiation of weight gain coincident with maximal PRP synthesis (Asquith et al., 1985). The size of the parotid gland and the production of PRP is greater in ruminant animals which naturally consume a large portion of their diet as browse, high in tannin (Robbins et al., 1987). Although unknown, cattle may have the capacity to adapt to high condensed tannin levels by dramatically increasing the production of PRP. Proline-rich protein production and elevated salivary flow could explain greater chyme flow through the duodenum, increased N flow from the rumen and greater ruminal starch digestion for bird resistant sorghum grain reported by Hibberd et al. (1985) and Streeter et al. (1989a).

Starch and protein supply to the rumen may alter the composition of bacteria. Ruminal bacteria under N limiting conditions can accumulate intracellular polysaccharides (McAllen and Smith, 1974). Data obtained by McAllen and Smith (1976, 1977) indicate that starch diets lead to prolonged periods of bacterial polysaccharide accumulation compared to diets containing greater amounts of soluble sugar when N is limiting. Results obtained by Bergen et al. (1968) suggest that bacterial protein composition, amino acid composition and digestibility are not affected by diet. Further study is needed to determine the effects of bacterial polysaccharide accumulation on the efficiency of microbial protein synthesis in the rumen and starch digestion in the small intestine. A portion of the observed, lower than expected digestion of cereal grain starch in the small intestine may be due to bacterial polysaccharides or glycoproteins.

Intestinal Starch and Protein Digestion

Starch digestion in the intestines is influenced by many of the same factors influencing ruminal digestion. Levels of DM and starch intake and grain processing may have the greatest effects on digestion. Increases in the rate of passage through the intestines could decrease the time allowed for digestion in a manner similar to ruminal digestion. However, the rate of chyme movement through the small intestine is generally less variable than observed for the rumen (Owens et al., 1986). Sorghum grain variety tends to alter digestion in the small intestine in a manner similar to ruminal observations.

Ruminal starch digestion is decreased as DM and starch intake is elevated; consequently, the amount of starch flowing to the small intestine increases (Karr et al., 1966; Nicholson and Sutton, 1969; Galyean et al., 1979; Zinn and Owens, 1980; Russell et al., 1981). Owens et al. (1986), in a recent review, concluded that the digestibility of starch in the small intestine (% of intake) increases with greater starch flow to the small intestine, if ruminal escape of readily degradable starch is increased. Additionally, no ceiling to starch digestion in the small intestine was detected. Therefore, it would appear that enzyme levels did not limit starch digestion in the studies reviewed. Enhancing enzyme activity may still be beneficial to starch digestion within the small intestine. Factors, such as rapid passage rate and large particle size (Kim and Owens, 1985) that could limit starch digestion in the small intestine may be partially alleviated by greater amylase concentration or activity. Harbers and Davis (1974) reported that pancreatic amylase could diffuse through only one layer of grain cell wall to digest underlying starch granules.

Greater amylase concentration would increase the rate of amylase diffusion into grain particles.

Amylase, maltase and isomaltase have been implicated by Armstrong and Smithard (1979) as enzymes potentially limiting starch digestion in the small intestine of ruminants. Concentrate feeding may reduce the pH of the small intestine to a suboptimal level for amylase activity, or an inadequate amount of amylase maybe secreted into the small intestine (Armstrong and Smithard, 1979). Recent work conducted by Remillard and Johnson (1984) suggests that starch hydrolysis in the small intestine of feedlot cattle is not limited by insufficient amylase secretion or depressed chyme pH. However, secretion of pancreatic amylase varies with animal age and diet composition (Siddons, 1968). Starch hydrolysis is most rapid when amylase is associated with intestinal mucosa (Owens et al., 1986); therefore, suboptimal intestinal pH and abrasive digesta may affect starch digestion in the small intestine by adversely altering the intestinal mucosa. Total starch intake can influence enzyme production and excretion. Pancreatic amylase activity from steers fed high concentrate diets was 140% that of pancreatic tissue from similar steers grazing wheat pasture as reported by Clary et al. (1969). Russell et al. (1981) reported that the percentage starch in the diet also influenced pancreatic amylase activity. Thus, as cattle are maintained on high concentrate diets for longer periods of time, amylase activity may increase. Therefore, although feedlot step-up programs have been traditionally viewed as a method of slowly allowing microbial adaptation to high concentrate diets, important enzymatic changes in the small intestine also likely occur. Such an adaptive

response has been suggested in non-ruminants (Johnson et al., 1977). In rats, increased production of amylase was only possible when the diet contained high quality protein (Johnson et al., 1977). Hence, greater escape of low quality grain protein from ruminal degradation may adversely affect essential amino acid flow to the small intestine, subsequently, amylase activity and starch digestion within the small intestine may be limited. Whether essential amino acid flow to the small intestine is inadequate for enzyme synthesis or some other factor related to starch digestion, such as glucose absorptive sites, is unclear. However, in some trials with ruminants (Rust et al., 1979; Veira and Macleod, 1980), additional dietary protein has increased total tract digestion of starch. A portion of the increase in total tract starch digestibility may be due to elevated ruminal ammonia level enhancement of ruminal starch digestibility.

When DM or starch intake is increased, fermentation in the large intestine becomes an important consideration (Karr et al., 1966; Russell et al., 1981; DeGregorio et al.,1982). Early studies attempting to quantify intestinal digestion of starch did not distinguish between digestion in the small and large intestines. Work conducted by Hibberd et al. (1985) has shown that the large intestine may compensate for poor starch digestion in the rumen and small intestine. The large intestine appears to have great variation in its ability to digest starch; however, little work has been conducted looking directly at starch digestion in the large intestine. Galyean et al. (1979) observed the amount of starch in the feces increased as feed intake increased. Starch digestion in the large intestine, expressed as a percent of entry, decreased 20% as feed intake increased

from 1.5 to 2.0% of body weight in a study by Zinn and Owens (1980). Grams of starch excreted in the feces also increased (10.6 to 63.0 g) as feed intake increased.

Orskov et al. (1970) infused starch into the large intestine of sheep and suggested that the large intestine has a limited capacity to digest starch. Starch in excess of 138 g/d (8.7 g/kg metabolic body weight) reaching the large intestine appeared in the feces. Karr et al. (1966) working with cattle reported starch disappearance in the large intestine to be 4.3 g/kg metabolic body weight with 83% of starch flowing to the cecum digested. Streeter et al. (1989a) reported a range of 3.3 to 6.7 g of starch/kg of metabolic weight digested in the large intestine; however, the digestibility of starch in the large intestine did not vary among diverse sorghum grain varieties (51.9%). Goetsch and Owens (1984) infused soluble starch into the ileum of steers and noted an increase in hindgut passage rate, suggesting less time allowed for fermentation to occur as more starch reached the cecum. Orskov et al. (1970) suggested a limited capacity for starch fermentation in the large intestine. However, the digestibility of starch in the large intestine appears to be related to the amount of starch flowing to the large intestine and N availability within the large intestine.

Nitrogen absorption from or diffusion into the large intestine is dependent on the amount of starch available for fermentation, much like N recycling to the rumen. Total tract apparent N digestibility may be depressed by starch fermentation in the large intestine, due to microbial trapping of undegraded enzymes from the small intestine, of undegraded feed and microbial N and of urea-N recycled from blood

plasma to the large intestine (Orskov, 1982). Fecal N excretion is increased by ileal starch infusion (Orskov et al., 1970; Goetsch and Owens, 1984). However, starch infused into the ileum has not passed through the digestive tract and should be more easily fermented, with a larger proportion potentially degradable, than residual feed starch reaching the cecum. When Mason et al. (1977) infused gelatin into the cecum, to provide excess N, blood urea levels were elevated, presumably from N diffusion out of the large intestine. Therefore, although fermentation in the large intestine results in a loss of N in the form of bacterial N, the majority of increased N excretion appears to be derived from the non-essential N pool. So, if N were not utilized to support microbial growth in the large intestine, N would be excreted as urea in the urine (Mason et al., 1977). Although, starch digestion prior to the cecum is desirable, fermentation in the large intestine does result in the capture of VFA from starch that otherwise would be excreted.

Effective grain processing methods make starch more susceptible to ruminal and small intestinal digestion; however, because ruminal fermentation occurs prior to the small intestine reduced amounts of starch generally reach the small intestine (Cole et al., 1976a; Galyean et al., 1976; Hibberd et al., 1985; Hinman and Johnson, 1974a,b; McNeill et al., 1971; Osman et al., 1970). McNeill et al. (1971) reported postruminal sorghum starch digestion was enhanced by steam flaking (98.4%), reconstitution (98.4) and micronization (95.0) over dry grinding (94.4). Although the above study did not distinguish between the large and small intestines, ruminal data would indicate that the capacity of the small intestine was probably not exceeded;

therefore, processing should decrease the amount of starch entering in the large intestine. Owens et al. (1986), in reviewing recent studies, concluded that grain processing increases starch digestion in the rumen and small intestine. However, because processed grain passes through the rumen first, ruminal starch digestion may be enhanced more than starch digestion in the small intestine.

The effect of grain processing on starch digestion in the large intestine has received only limited study. Hibberd et al. (1985) reported increased starch digestion in the rumen and small intestine for reconstituted compared to dry rolled sorghum grain, while starch fermentation in the large intestine was slightly decreased due to reconstitution. Reduced digestion in the large intestine with extensive grain processing likely results from extensive digestion prior to the cecum limiting starch available for fermentation. Additionally, residual starch reaching the large intestine may be more heavily encapsulated in protein and comprised of more limit dextrins than less extensively digested (processed) starch.

The digestion of N in the small intestine appears to be very constant considering the supply of N consists of three diverse protein supplies (microbial, residual feed and endogenous N). Zinn and Owens (1982a) reported small intestinal N digestion to be closely grouped around 69% ($\pm$ 3%). Hibberd et al. (1985) reported that sorghum grain variety altered N disappearance in the small intestine and reconstitution of sorghum grain increased N disappearance in the small intestine.

Zinn and Owens (1982b) summarized several studies involving pure bacterial cultures and ruminal isolates, suggesting a wide range of

apparent postruminal bacterial N digestibility due to large intestinal fermentation associated with diet type and feed intake. Potter et al. (1971) demonstrated that true post ruminal digestion of total N in steers fed processed sorghum grain differed very little, even though the origin (microbial versus feed) of N differed greatly between processing methods. The protein source in concentrate diets may influence N digestion in the small intestine (Zinn and Owens, 1983b). Zinn and Owens (1981, 1983a) demonstrated that increasing feed intake from 1.2 to 2.2% of body weight linearly increased N disappearance in the small intestine. Increases associated with feed and starch intakes may be caused by faster ruminal turnover resulting in greater amounts of soluble, readily degradable protein reaching the small intestine.

Nitrogen Flow to the Duodenum and Microbial Efficiency

Microbial protein constitutes an extremely important source of N reaching the small intestine. From 40 to 80% of the available protein reaching the duodenum comes from microbial protein (Owens and Bergen, 1983). Nitrogen flow may be affected by such factors as level of feed intake, roughage to concentrate ratio, and physical form of the ration. Factors associated with alterations in N flow and(or) efficiency of microbial protein production may also influence ruminal liquid dilution rate.

Feed intake increases result in greater total N flow to the small intestine. Zinn and Owens (1983a) reported a 59% increase in total N flow to the small intestine as feed intake increased from 1.2 to 2.1 % of body weight. Similarly, feed N escaping ruminal degradation

increased 38% and microbial N reaching the duodenum increased 48%. Effects of increasing feed intake may be the direct result of an increased amount of substrate available to the ruminal microbes and an increased ruminal liquid dilution rate (Zinn and Owens, 1980; Bergen et al., 1982).

Level of roughage may also greatly influence N flow and efficiency of microbial protein production through changes in salivary flow and ruminal liquid dilution rate. Cole et al. (1976b) noted a substantial increase in N reaching the small intestine (70.3 vs 126.3 g/day) as roughage level increased (0% to 21%). At higher roughage levels (14 to 21%), N reaching the small intestine exceeded N intake by 18.3% and 7.6%, respectively, indicating greater N recycling caused by an increase in salivary flow (Cole et al., 1976b). Microbial N reaching the duodenum tended to increase with roughage; however, as a percent of total N reaching the small intestine, little difference existed between treatments. Faster ruminal liquid dilution rates, which may result from increased salivation with higher roughage diets, have been shown by Issacson et al. (1975) to enhance the efficiency of microbial protein production in vitro. Froetschel et al. (1989) noted a linear increase in the efficiency of microbial protein synthesis when salivary flow was artificially stimulated in cattle. Weakley (1983) demonstrated that the efficiency of microbial protein production in vivo increases with roughage level.

The physical form of the diet alters N flow and efficiency of microbial protein production. Cole et al. (1976b) reported greater total N flow through the abomasum for dry rolled corn versus steam flaked corn. All protein fractions showed an increase (non-ammonia N,

18%; microbial N, 14%; feed bypass N, 21%). A 34% increase in efficiency of microbial protein synthesis was observed for dry rolled corn over steam flaked corn diets. Cole et al. (1976b) suggested rations that should have more rapid fermentation rates (steam flaked corn and lower roughage rations) may have lower microbial protein synthesis per unit of dry matter fermented. Zinn et al. (1981) suggested a large portion of energy from highly fermentable feeds normally used for protein synthesis may be diverted to produce microbial polysaccharides for storage thereby reducing the efficiency of microbial protein synthesis. Increases in total N reaching the duodenum have been associated with reconstituted sorghum grain (Hibberd et al., 1985) and ground high moisture harvested corn (Prigge et al., 1976), when compared to their respective dry rolled counterparts. Hibberd et al. (1985) reported increased chyme flow associated with reconstitution suggesting that ruminal liquid dilution rate may have been increased. Prigge et al. (1978) reported that steam flaked and ground high moisture corn had a greater microbial efficiency than dry rolled corn. Acid treatment of high moisture corn further enhanced the efficiency of microbial protein production above that observed for ground high moisture corn (Prigge et al., 1978). Streeter et al. (1989f) reported a linear increase in the efficiency of microbial protein production when high moisture sorghum levels increased and dry rolled corn decreased in the diet. Moreover, duodenal chyme flow and ruminal pH increased with the addition of high moisture sorghum. Increasing ruminal liquid dilution rate reduces the maintenance requirements of the microbes; thereby, increasing the efficiency of microbial protein production (Bergen and Yokoyama, 1977). Chemical and

physical factors that alter ruminal turnover rate should, therefore, be useful in increasing the efficiency of microbial protein synthesis. Cole et al. (1976b) noted a 36% increase in microbial efficiency as dilution rate increased from 2.8 to 5.0 %/h. Maintenance may also be affected by the presence of growth inhibiting substances (Bergen and Yokoyama, 1977) such as condensed tannins (Benson et al., 1984).

Solid retention time has also been implicated as a potentially important factor affecting the efficiency of microbial protein production in vitro (Crawford, et al., 1980). No significant effect of liquid dilution rate was observed by Crawford et al. (1980); however, decreasing solid retention time increased the efficiency of microbial protein synthesis. In vivo, one would expect passage of bacteria from the rumen to be related to the rate of solid flow because 50% or more of ruminal bacteria are attached to feed particles. However, as liquid dilution rate increases solids are likely carried out of the rumen more rapidly. Further study is needed to determine the importance of particulate passage rate on the efficiency of microbial protein synthesis and N flow to the duodenum.

Use of Cannulated Animals

Information from intestinally cannulated animals has improved the understanding of site and extent of digestion of starch, protein and fiber. Re-entrant intestinal cannula, such as described by Ash (1962), have been used widely because they permit total collection of digesta. Total digesta collection helps prevent non-representative sampling errors; however, a properly placed, open T-shaped cannula (a vertical plane being optimal) also should enable researchers to collect

representative digesta samples (MacRae and Wilson, 1977; McGilliard, 1982). Non-representative samples of digesta may result from formation of a pocket of intestine allowing digesta to pool and separate. Deterioration of the intestine around the fistula causes pocket development. Pockets can form with either re-entrant or closed T-shaped cannula.

T-type cannulae offer several advantages over re-entrant cannulae. During re-entrant cannulation, the intestine must be transected. Such transection reduces or alters intestinal motility (Wenham and Wyburn, 1980). Most re-entrant cannulae externalize digesta flow through a relatively non-elastic tube. Lack of elasticity and natural propulsion of digesta in the external tube may restrict digesta flow and result in intestinal blockage. Increased resistance to flow may increase the rate of intestinal deterioration and the potential for pool formation (McGilliard, 1982). Intestinal blockage is particularly evident with high fiber diets (Ash, 1962). Another important limitation of re-entrant intestinal cannulae is the exposure of the external portion of the cannula to physical or mechanical disturbance during animal activity. Mechanical trauma of the cannula undoubtedly increases scar tissue development and reduces muscular and intestinal integrity around the fistula (McGilliard, 1982).

Komarek (1981) developed a rigid, closed T-shaped cannula that allowed total digesta collection without externalization of digesta flow or transection of the intestine. However, a lateral incision in the intestine of a minimum of 57 mm was required for cannula insertion. Although a lateral incision is less likely to alter motility than transection, a smaller incision should reduce the probability of

disrupting motility. Additionally, a boot around the cannulated intestine is needed to prevent digesta from flowing around the cannula. Insertion of this boot requires separation of the mesentery from the intestine potentially disrupting nervous innervation and blood flow to the cannulated area. Digesta flow around the boot surrounding the cannula may result in non-representative digesta sampling, formation of a separation pool in the intestine and cannula failure (McGilliard, 1982).

T-shaped intestinal cannulae that do not allow total digesta collection ideally allow collection of representative digesta samples based on the physical principles of fluid flow (MacRae and Wilson, 1977). Various materials have been used in construction of open T-type cannulae; prevention of mechanical damage to the intestine and subsequent formation of separation pools have been the primary concerns (McGilliard, 1982). Tygon tubing glued with cyclohexanone and molded Plastisol have been used for cannula construction because of their flexibility. Flexibility of construction materials reduces the risk of mechanical damage to the gastrointestinal tract and development of scar tissue around the fistula resulting from physical irritation. However, T-type cannulae are not easily removed from the fistula and replacement of the cannula can cause mechanical damage to intestinal tissue and the development of scar tissue. Additionally, the flexible nature of the flanges of the one piece cannula may irritate the intestinal wall around the fistula.

CHAPTER III

A DOUBLE L INTESTINAL CANNULA FOR CATTLE[1]

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ABSTRACT

A double L-shaped intestinal cannula was designed in an attempt to overcome some of the problems observed with other types of cannulae. The cannula was constructed from cyclopolyvinyl chloride water pipe and fittings. Despite rigid construction, connecting split cannula pieces with elastic castration bands provided some flexibility and permitted easy installation and removal. Mechanical disturbance to the cannula was reduced by exposing only a short cone shaped barrel to the exterior of the body surface.

(Key words: Cannula; Intestine; Cyclopolyvinyl Chloride; Ruminants)

Introduction

Information from intestinally cannulated animals has improved the understanding of site and extent of digestion of starch, protein and

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fiber. Re-entrant intestinal cannula, such as that described by Ash (1962), have been used widely because they permit total collection of digesta. Total digesta collection helps prevent non-representative sampling errors; however, a properly placed open T-shaped cannula (a vertical plane being optimal) also should enable researchers to collect representative digesta samples (MacRae and Wilson, 1977; McGilliard, 1982). Non-representative samples of digesta may result from deterioration of the intestine around the fistula which results in the formation of a pocket of intestine allowing digesta to pool and separate. Pockets can form with either re-entrant or closed T-shaped cannula.

T-type cannulae offer several advantages over re-entrant cannulae. During re-entrant cannulation, the intestine must be transected. Such transection reduces or alters intestinal motility (Wenham and Wyburn, 1980). Most re-entrant cannulae externalize digesta flow through a relatively non-elastic tube. Lack of elasticity and natural propulsion of digesta in the external tube may restrict digesta flow and result in intestinal blockage. Increased resistance to flow may increase the rate of intestinal deterioration and the potential for pool formation (McGilliard, 1982). Intestinal blockage is particularly evident with high fiber diets (Ash, 1962). Another important limitation of re-entrant intestinal cannulae is the exposure of the external portion of the cannula to physical or mechanical disturbance during animal activity. Mechanical trauma of the cannula undoubtedly increases scar tissue development and reduces muscular and intestinal integrity around the fistula (McGilliard, 1982).

Komarek (1981) developed a rigid, closed T-shaped cannula that allowed total digesta collection without externalization of digesta flow or transection of the intestine. However, a lateral incision in the intestine of a minimum of 57 mm was required for cannula insertion. Although a lateral incision is less likely to alter motility than transection, a smaller incision should reduce the probability disrupting motility. Additionally, a boot around the cannulated intestine is needed to prevent digesta from flowing around the cannula. Insertion of this boot requires separation of the mesentery from the intestine potentially disrupting nervous innervation and blood flow to the cannulated area. Digesta flow around the boot surrounding the cannula may cause non-representative digesta sampling, formation of a separation pool in the intestine and cannula failure (McGilliard, 1982).

T-shaped intestinal cannulae that do not allow total digesta collection ideally allow collection of representative digesta samples based on the physical principles of fluid flow (MacRae and Wilson, 1977). Various materials have been used in construction of open T-type cannulae; prevention of mechanical damage to the intestine and subsequent formation of separation pools have been the primary concerns (McGilliard, 1982). Tygon tubing glued with cyclohexanone and molded Plastisol have been used for cannula construction because of their flexibility. Flexibility of construction materials reduces the risk of mechanical damage to the gastrointestinal tract and development of scar tissue around the fistula resulting from physical irritation. However, T-type cannulae are not easily removed from the fistula and replacement of the cannula can cause mechanical damage to intestinal tissue and the

development of scar tissue. Additionally, the flexible nature of the flanges of the one piece cannula may irritate the intestinal wall around the fistula. Hence, a new open double L-shaped intestinal cannula based on the esophageal plug initially described by Walker et al. (1985) was designed to eliminate some of these disadvantages.

Materials and Methods

The double L-type intestinal cannula was constructed from 19 mm (3/4 in.) cyclopolyvinyl chloride (CPVC) pipe and fittings. The materials required for cannula construction were 1-19 mm o.d. (3/4 in.) tee; 1-19 mm o.d. (3/4 in.) coupler cut into 4 pieces each 5 mm long; 130 mm of 19 mm o.d. (3/4 in.) CPVC pipe cut into sections 38, 38 and 51 mm long; CPVC glue; 2 elastic castration bands; 1-19 mm i.d. (3/4 in.) ballcock washer; 1-63.5 (2 1/2 in.) x 7 mm (1/4 in.) bolt and jam nut; 60 mm of vacuum tubing; 1-25 o.d. (1 in.) x 7 mm i.d. (1/4 in.) fender washer and 1-14 o.d. (1/2 in.) x 7 mm i.d. (1/4 in.) standard flat washer. The pipe and fitting are standard nominal measurements of schedule 40 CPVC.

Construction of the cannula (Figure 1) is begun by gluing a 38 mm piece of 19 mm pipe (c) into each arm of the tee (a) and a 51 mm piece (d) into the base. Next a 5 mm section of coupler (b) is glued over the tip of the pipe (d) with the coupler and the end of the pipe being flush. Glue is allowed to cure for 12 hours or overnight. This T-shaped cannula is then cut into two halves by cutting the arms of the tee in half on a plane perpendicular to the base and cutting the barrel on a plane perpendicular to the long axis of the arms (Figure 1).

Next, edges must be smoothed to the form shown in Figure 2. The ridges created by the intersection of the tee and the pipe are removed with a bench grinder equipped with a wire wheel. The flange is shaped by grinding with an emery wheel on a bench grinder. The flanges should be 25 to 31 mm in length after shaping is complete. The bottom edges of the flanges should be sloped upward toward the barrel of the cannula where the two L-shaped pieces of the sidearms will join. Sloping the base of the flanges simplifies insertion of cannulae during surgery and replacement after surgery. Shaping of the flanges also allows one to minimize the size of the lateral incision (<20mm) in the intestine during surgery; this compares with a much larger incision for cannulae described by Komarek (1981) or Hecker (1974). After the basic shape is obtained, each piece is sanded with coarse (No. 40) and subsequently with fine (No. 150) sandpaper until all rough edges are smooth. Ridges on the flanges created by the tee may still be visible, but they should be smooth. Finally, the tips of the flanges are heated utilizing a Bunsen burner and rolled under slightly to prevent them from irritating the intestine. The heated area must be sanded again with fine sand paper to remove any bubbles in the CPVC caused by heating. The L-shaped cannula pieces are complete when all edges exposed to the body surfaces are smooth. The L-shaped pieces are held together, after surgical placement in the intestine, by two elastic castration bands placed near the coupler. The elastic bands provide some flexibility to prevent serious physical damage to the intestinal tract in the event of a mechanical trauma to the cannula.

The stopper used to close the cannula when collections are not being made is formed by sequentially placing on the 63.5 mm bolt the

fender washer, 60 mm of vacuum tubing, a standard flat washer and jam nut (Figure 2). The nut is tightened so that the plug fits snugly in the cannula. Threads at the end of the bolt are macerated with a hammer to prevent removal of the nut. The length of the stopper is extremely important. The bolt used in the construction of the cannula plug should be 13 mm longer than the piece of CPVC pipe used to form the barrel of the cannula. If the stopper is not as long as the barrel of the cannula, the cannula will leak because of the two piece cannula design. However, when the stopper is of the correct length, leakage has been slight or non-existent. The tapered rubber ballcock washer is placed over the exteriorized barrel of the cannula. The rubber washer should fit snugly between the body and the elastic castration bands to hold the cannula securely in place (Figure 3).

Results and Discussion

Animals recovered from surgery rapidly even when both duodenal and ileal cannulae were inserted. Development of scar tissue was greatly reduced compared to that noted for cattle previously outfitted with open T-type cannulae constructed of Tygon tubing. After healing of the area, the barrels of the cannulae were exteriorized from the body to the same magnitude as was observed shortly after surgery, indicating that development of scar tissue was minimal. These cannulae remained much cleaner throughout their use than did Tygon type cannulae with very minimal leakage of digesta and exudate of leucocytes. Perhaps this is the result of less irritation to the intestinal tract, or the fact that material used in construction of the cannula was less biologically reactive than Tygon tubing (McGilliard, 1982). Steers

were easily maintained and sampled; they survived and grew normally for the duration of the trials (2.5 years). During sampling of digesta, collection was simplified by the placing a 19 mm (3/4 in.) polyvinyl chloride (PVC) elbow over the end of the cannula barrel to direct digesta flow into a collection bottle.

The intestinal cannula described was used for cattle weighing approximately 230 kg. The length of the cannula barrel may need to be increased to accommodate the added thickness of the body wall of larger or more mature animals. The cannula design offers several advantages over other types. The cannula and accompanying ballcock washer resulted in a close fitting, cone shaped, external profile to minimize the probability of external mechanical trauma.

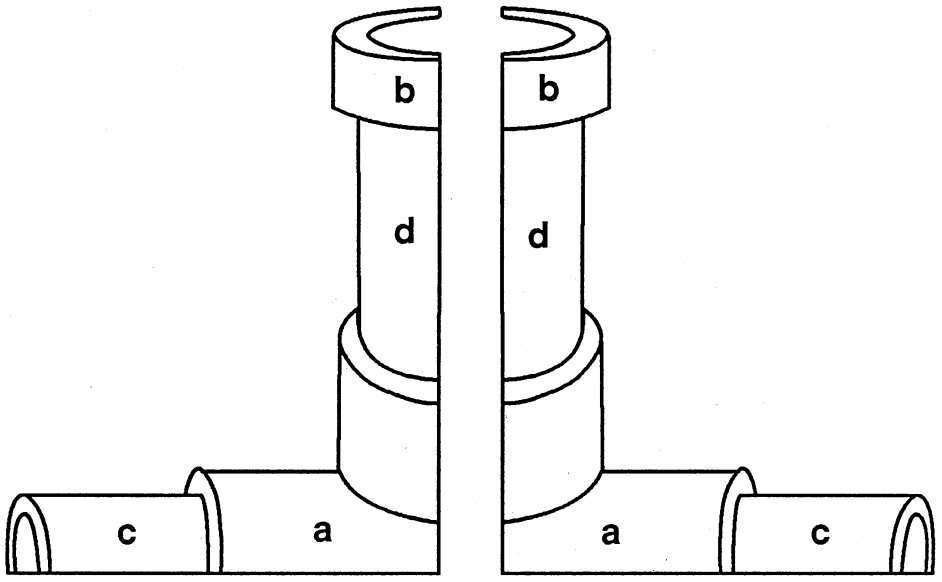

Figure 1. Illustration of the Intestinal Cannula for Cattle after Gluing and Cutting to Form Double L-shape (a = 19-mm CPVC tee, b= 1/4 of a 19-mm CPVC coupler, c = 38 mm section of 19-mm CPVC pipe, d = 51 mm section of 19-mm CPVC pipe).

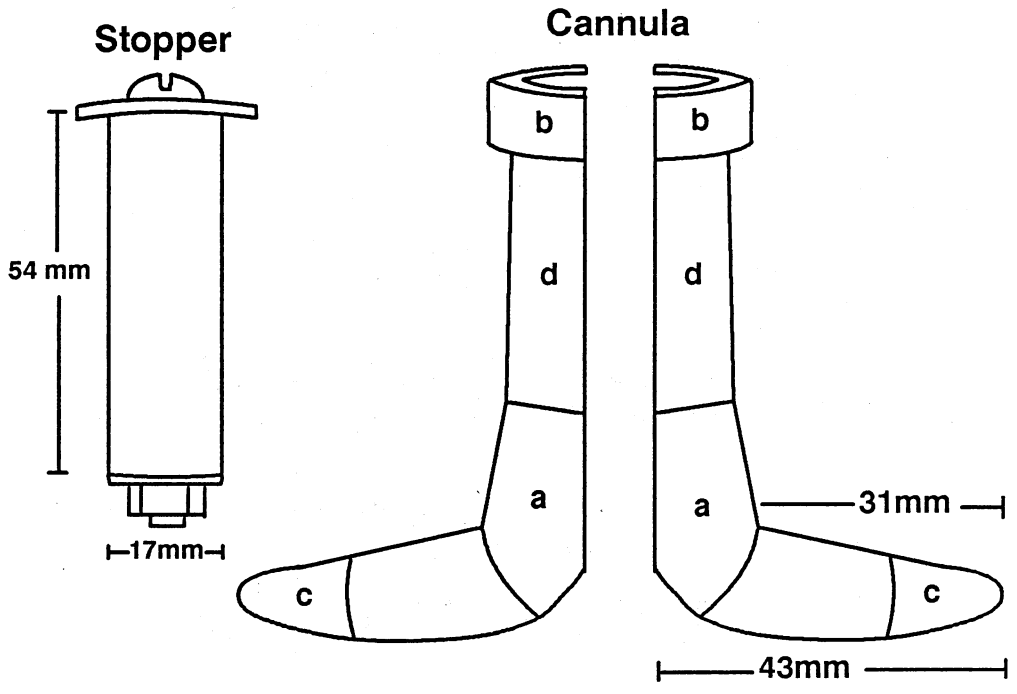

Figure 2. Illustration of a Properly Shaped and Sanded Double L Cannula and Stopper.

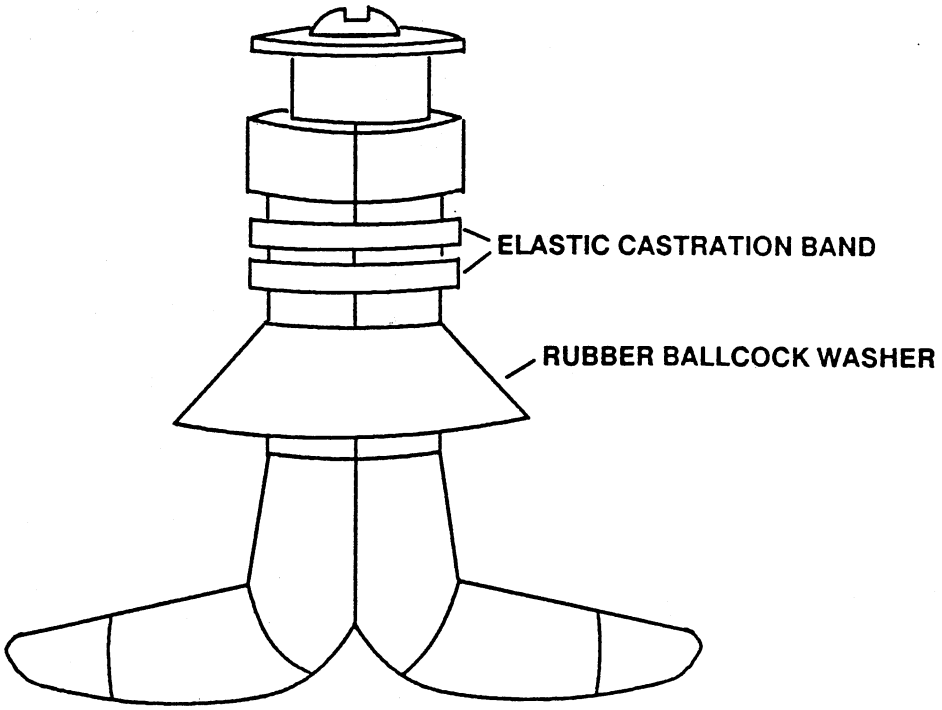

Figure 3. Illustration of a Completed Double L-shaped Cannula.

CHAPTER IV

COMPARISON OF CORN WITH FOUR SORGHUM GRAIN HYBRIDS: SITE AND EXTENT OF DIGESTION IN STEERS[1,2]

M.N. Streeter, D.G. Wagner, C.A. Hibberd and F.N. Owens

ABSTRACT

Four sorghum hybrids (yellow, cream, hetero-yellow and red and corn grain were dry rolled and fed in an 85% grain diet to Angus-Hereford steers (241 kg) equipped with permanent ruminal and duodenal and ileal double L type intestinal cannulae to compare the effects of grain source on site and extent of digestion. Yellow (yel) has a homozygous yellow endosperm, with a yellow seed coat, whereas, cream and hetero-yellow (het-yel) have a heterozygous yellow endosperm with white and red seed coats, respectively. Red has a homozygous white endosperm with a red seed coat. Diets were fed at 2% of body weight (DM basis) in a 5 X 5 Latin square. Total tract starch digestibility (%) was greater ($P<.05$) for corn (92.5) than for red (84.3), yel (84.3) and het-yel (82.9), but not greater than ($P>.10$) cream (87.9). Ruminal starch digestibility (%) was greater ($P<.10$) for corn (85.8) than for

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[2]The assistance of Dr. Dave Buchanan with statistical analysis is greatly appreciated.

the mean of all sorghum hybrids (69.1). Pre-cecal starch digestibility (%) was greater (P<.05) for corn (90.6) than het-yel (76.2), red (74.8) and yel (74.1). Quantitatively, slightly more dietary starch was digested in the small intestine from het-yel (11.0), red (10.4), and cream (9.8) than from corn (5.1) or yel (4.6). Ruminal escape of grain N (%) was greater (P<.10) for red (79.9) than het-yel (69.2), cream (66.5) and yel (66.1), while the value for corn (53.6) was less than (P<.10) the average of all sorghum hybrids. Pre-cecal non-NH_3 N (NAN) digestibility and total tract NAN digestibility were not altered (P>.10) by grain source. Hybrid of sorghum altered site and extent of starch digestion and ruminal escape of grain N in cattle and in the rolled form had predicted feed efficiencies at 81 to 93% of rolled corn grain.

(Key Words: Sorghum Grain, Corn, Starch, Protein, Digestion, Beef Steers.)

Introduction

Corn and sorghum grain are commonly fed in feedlot diets. Sorghum grain requires less water to grow and can be grown successfully under a wider variety of conditions than corn. However, sorghum grain is more variable in quality than corn, due to because of environmental influences (Wall and Ross, 1970), but also potential varietal and hybrid differences (Miller et al., 1962). Variation in cattle performance associated with different sorghum grain hybrids or varieties (McCollough et al., 1972; Maxson et al., 1973) may be due partially to differences in digestibility (McCollough and Brent, 1972). Comparing sorghum grain with a pure yellow endosperm to corn, Brethour

(1987) noted no differences in rate and efficiency of gain by beef steers. Goldy et al. (1987) reported no statistical advantage in growth rate or efficiency of gain by steers fed a homozygous yellow endosperm sorghum hybrid compared to those fed heterozygous yellow endosperm sorghum hybrid differing in seed coat color. Nevertheless, ADG by steers were 8% lower with a homozygous yellow and 11% lower with a hetero-yellow endosperm sorghum grain than with corn.

Differences in site and extent of digestion have been noted with pureline sorghum grain varieties (Streeter et al., 1989b); therefore, one might expect differences among various hybrids (Norris and Rooney 1970). Endosperm characteristics and ruminal fermentation and intestinal digestion may differ among sorghum grain hybrids (Black, 1971). The objective of this study was to quantify the differences between four sorghum grain hybrids and corn in chemical composition, in extent of starch digestion within the rumen, the small and large intestines, and in extent of grain protein escape to the small intestine in beef cattle.

Materials and Methods

Yellow (Paymaster 1096 Y), cream (PAG 575), hetero-yellow (PAG 5572) and red (PAG 4433)[3] sorghum grain hybrids were grown under dryland conditions during the summer of 1986 in southeastern Kansas. Corn was purchased commercially. Yellow (yel) has a homozygous yellow endosperm with a yellow seed coat. Cream has a heterozygous yellow endosperm with a white seed coat. Hetero-yellow (het-yel) has a

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[3]Sorghum grain seed donated by the Cargil Corporation is greatly appreciated.

heterozygous yellow endosperm with a red seed coat. Red has a homozygous white endosperm with a red seed coat (Table 1).

Laboratory Trial

Grain and diet samples were ground through a 1-mm screen prior to chemical analysis and through a .4-mm screen prior to starch analysis. Dry matter, CP, OM (AOAC, 1975), starch as alpha-linked glucose (MacRae and Armstrong, 1968, modified by the use of a glucose determination kit[4]), and ADF (Goering and Van Soest, 1970) content were determined. Grains additionally were analyzed for pepsin[5] insoluble nitrogen (PIN; Goering and Van Soest, 1970) and sodium chloride soluble nitrogen (NaCl-N; Waldo and Goering, 1979). Berry size of sorghum grain hybrids was determined by weighing 100 pre-dried berries selected randomly; their volume was determined by measuring the volume of toluene displaced by 100 dry berries. Density was calculated by dividing the dry mass of 100 berries by the volume displaced. Geometric mean diameter (GMD) of dry rolled grain particles was determined by the procedure of Ensor et al. (1970). Relative distribution of particles among sieves and GMD have been used as indirect determinations of hardness (corneousness) of wheat (Obuchowski and Bushuk, 1980) and of sorghum grain (Pomeranz, 1986).

Animal Trial

Five Angus-Hereford steers (241 kg $\pm$ 6.2) were surgically fitted, while under local anesthesia, with permanent ruminal and double L

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[4]Glucose oxidase, Sigma Chemical Co., St. Louis, Mo., USA.

[5]Sigma Chemical Co., St. Louis, Mo., USA.; EC 2.4.23.1

duodenal (4 cm distal to the pylorus) and ileal (20 cm cranial to the ileo-cecal junction) cannulae (Streeter et al., 1989d). Steers were fed diets containing one of the four sorghum grain hybrids or corn (Table 2) at 2% (DM basis) of body weight in a 5x5 Latin square. Feed intake was lower than usually noted in a feedlot or production situation (ad libitum), but consistently higher intakes were difficult to maintain under our experimental conditions. Diets were formulated to meet NRC (1984) requirements for CP, Ca and P for medium framed steer calves gaining .6 kg/d. Urea was used as the sole source of supplemental N, and cottonseed hulls (which at 4.1% N, provided approximately 2.6% total dietary N) were used as the roughage source so that feed N reaching the duodenum would be primarily of grain origin (approximately 90.0%). Liquid molasses was included at 3% of diet DM (containing approximately 2.0% of total dietary N) to reduce dust. Chromic oxide (.20% of diet DM) was used as an indigestible marker.

Experimental periods lasted 14 d, with d 1 through 11 for diet adaptation and 12 through 14 for feed, digesta and fecal sampling. Steers were fed equal portions of feed at 0800, 1400 and 2000. Steers were pulse dosed with 1 g of ytterbium (Yb) in the form of Yb-labeled grain (Teeter et al., 1984) and 1 g of cobalt (Co) in the form of Co·EDTA (Uden et al., 1980) at 0800 on d 12 of each period. Digesta samples were collected at 1200, 1800 and 2400 on d 12, 0600, 1500 and 2100 on d 13 and 0300 and 0900 on d 14. This schedule allowed collected samples to represent every third h of a 24-h period. Digesta (250 ml duodenal and 250 ml ileal fluid/sample) and fecal grab samples, after pH determination, were composited across time and d within steer and stored at 2^{o} C until the end of each period. An additional, 150 ml

of duodenal fluid was obtained at each sampling time, immediately dried at 55° C for 48 h in a forced-air oven and ground through a 1-mm screen for later Yb and Co analysis. For ammonia determination, ruminal fluid for ammonia (NH_3-N) determination was collected at 1500 and 2100 on d 13 and 0300 and 0900 on d 14. Ruminal fluid samples were strained through four layers of cheesecloth and acidified (5 ml of 20% H_2SO_4 per 100 ml of fluid) immediately following determination of pH. Subsamples of ruminal, duodenal and ileal fluids and feces were obtained and stored at -20° C.

At 1400 on d 14 of periods 2, 3, 4 and 5 two liters of ruminal fluid was collected and strained through four layers of cheesecloth into collection flasks surrounded by ice for each steer to estimate microbial N, purine N, and OM. Within each period, equal volumes of ruminal fluid from each of the five steer were composited (Streeter et al., 1989f). Bacteria were isolated from composite ruminal fluid samples 1 d after collection by differential centrifugation (Weakley, 1983), frozen (-20° C), lyophilized and ground with a mortar and pestle prior to analysis.

Feed, digesta and fecal samples were lyophilized prior to grinding through a 1-mm screen for chemical analysis. Feed, duodenal, ileal and fecal samples were analyzed for chromic oxide (Fenton and Fenton, 1979) in addition to all components used in the laboratory trial except PIN and NaCl-N. Digesta and bacterial samples also were analyzed for purine N (RNA basis; Zinn and Owens, 1986). Ruminal NH_3-N was determined by the procedure of Brodrick and Kang (1980). Ammonia-N was extracted (30 ml of .1 N HCl/g DM for 24 h) from dried digesta and

fecal samples and measured in the resulting supernatant as described for ruminal fluid by Brodrick and Kang (1980).

Partial digestion coefficients and amounts of different components presented to and disappearing from segments of the digestive tract were calculated from chromic oxide concentrations and intakes. Chyme flows were calculated as chromic oxide intake (g/d) multiplied by the fractional chromic oxide concentration. Microbial N reaching the duodenum was calculated as duodenal purine N divided by the mean ratio ($18.37 \pm .582$) of purine N (RNA basis to total N in isolated microbes for the trial. Feed N (plus endogenous N) reaching the duodenum was calculated as duodenal N minus NH_3-N and microbial N. Organic matter reaching the duodenum was corrected for microbial OM based on means determined for microbial ash (19.9%) and CP (35.0%). True ruminal OM disappearance was used to calculate the efficiency of microbial protein synthesis (g microbial CP/kg OM truly fermented in the rumen). Particulate passage rate (%/h) and ruminal liquid dilution rate (%/h) were estimated by the slope of the regression of the natural logarithm of Yb and Co concentrations in duodenal DM, respectively, against time. Samples obtained at 4, 10 and 16 h were determined to be on the up-slope; hence, they were not included in regression analysis.

Statistical Analysis

The model describing data from the laboratory trial included grain source and duplicate. The model describing data from the animal trial included period, animal and grain source. Differences between least squares means were determined by protected least significant difference (Steel and Torrie, 1980).

Results and Discussion

Laboratory Trial

Starch content of grain DM (Table 3) tended to be greatest for red (79.6%) and lowest for corn (72.2) and het-yel (72.9) , with yel (78.7) and cream (78.3) being intermediate. Red (10.4%) contained more ($P<.05$) CP than cream (9.7), het-yel (9.6) and yel (9.5), while corn (10.0) was intermediate ($P>.05$). Variation in CP content among sorghum may result from genetic (Hibberd et al., 1982a,b) and environmental effects (Wall and Ross, 1970). Corn and yel contained more ($P<.10$) NaCl-N than het-yel. Small differences ($P>.10$) in PIN content between corn and sorghum hybrids were observed, with an average PIN of 12.2% of N in CP. Previously, differences in NaCl-N have been reported for waxy versus normal endosperm types (Lichtenwalner et al., 1978; Streeter et al., 1989a) or non-bird resistant versus bird resistant types (Hibberd et al., 1985). Differences in PIN have been inversely related to digestibility in comparison of waxy versus normal endosperm (Streeter et al., 1989a) or bird resistant and non-bird resistant types (Hibberd et al., 1985) though some ADF-N disappears during transit through the ruminant gut (Zinn and Owens, 1982; Nakamura et al., 1989).

Berry size (g/100 berries) was greater ($P<.05$) for het-yel (2.53) than for the other grains, while red (2.27) and yel (2.22) had larger ($P<.05$) berries than cream (1.98). Berry volume (μl/berry) was greater ($P<.10$) for het-yel (20.5) than for yel (18.0) or cream (15.5), but not different ($P>.10$) from red (19.0). Red and yel berries occupied greater ($P<.10$) volume than cream. Because berry volume increased with berry weight no differences in density were observed; mean density was

1.24 g/ml. Similar densities may preclude differences in starch content. Larger berry size and volume would be expected to result in smaller grain particles when grains are rolled with the same roller setting if grains do not differ in the amount of corneous endosperm or hardness. Nevertheless, geometric mean diameter (GMD) of rolled grain particles did not reflect either berry size or volume. Corn (4,692 μm) had a greater ($P<.10$) GMD of particles than all sorghum hybrids due to a wider roller spacing to accommodate the much larger corn kernel (10x larger than sorghum). However, within sorghum hybrids, het-yel (1,275 μm) had a larger ($P<.10$) GMD of particles than cream (928 μm) and red (982 μm). Yellow (1,110 μm) was greater ($P<.10$) than cream but not different ($P>.10$) from het-yel or red. Cream, which had the smallest berry size and volume, resulted in the smallest particle size, while het-yel, which had the largest berry size and volume, resulted in the largest particle size among sorghum hybrids. The relationship between berry size and volume and resulting particle size may reflect differences in the amount of peripheral endosperm of the sorghum hybrids (Pomeranz, 1986).

The distribution of sorghum particles presumably reflects potential differences in the amount of peripheral endosperm among grains. Het-yel had more ($P<.10$) particles > 2,828 μm than other sorghum grains, but less than ($P<.10$) corn. Red had more ($P>.10$) particles > 2,828 μm in size than did cream, but yel was not different from red or cream ($P>.10$). The most important differences occurred with 1,414 and 707 μm sized particles. Het-yel (79.8%) and yel (75.8%) had a larger proportion ($P<.10$) of 1,414 μm particles than cream (65.2%) and red (64.0%), while all sorghum hybrids were greater ($P<.10$)

than corn. Differences noted for 707 μm particles were the opposite of those observed for 1,414 μm particles. Red (15.2%) and cream (13.0%) had a greater (P<.05) proportion of 707 μm particles than yel (9.3%) and het-yel (7.3%), with all sorghum hybrids being greater than (P<.05) corn (.2%). The 177 μm particle fraction should be very rich in starch. Cream (11.9%) and red (10.6%) had more 177 μm particles (P<.05) than het-yel (3.8%) or corn (.2%), with yel (7.0%) not different from cream or het-yel (P>.10), but greater (P<.10) than corn. Sorghum usually has a much greater proportion of endosperm as peripheral cells than corn (Rooney and Miller, 1982). Sorghum grain peripheral endosperm cells have a high protein content and resist both physical and enzymatic degradation (Rooney and Pflugfelder, 1986). One might expect sorghum grains with more peripheral endosperm cells to result in larger mean particle size. A larger proportion of 2,828 and 1,414 μm particles likely reflect more peripheral endosperm which might result in lower digestibility. A higher proportion of 707 and 177 μm particles should indicate a higher proportion of floury endosperm, high in starch and low in protein. The 707 and 177 μm particles should be highly digestible because protein encapsulation of the starch granules should be low and this should represent floury rather than corneous endosperm of the grain.

Animal Trial

Total tract OM digestibility was highly correlated (r=.93; P<.001) to total tract starch digestibility; therefore, only total starch digestibility will be discussed (Table 4). Total tract starch digestibility was greater (P<.05) for corn (92.5%) than for yel

(84.3%), red (84.3%) and het-yel (82.9%), while cream (87.9%) was intermediate (P>.10). Spicer et al. (1986) also noted total tract starch digestibility was somewhat greater for corn than sorghum grain. In contrast, Brown et al. (1968) observed no difference in NFE digestibility between corn and sorghum grain. Waldo (1973), summarizing 51 comparisons of corn, sorghum grain and barley, reported no difference in total tract starch digestibility among these grain types. However, McCollough and Brent (1972) compared eight sorghum hybrids to three corn hybrids and noted that the greatest NFE digestibility was for corn (86.5%) and the lowest was for a hetero-yellow sorghum grain (71.3%). Rooney and Pflugfelder (1986) reported that hetero-yellow sorghum grain had a higher feeding value than a non-yellow endosperm grain. Hibberd et al. (1985) noted no significant differences in total tract starch digestibility among three sorghum grain hybrids including a bird resistant, and Streeter et al. (1989b) detected no differences among several pureline sorghum varieties. A negative correlation in our study between non-urea feed N intake (approximately 90% grain N) and total tract starch digestibility (r=-.66; P<.05) may indicate that protein encapsulation of starch granules reduced starch availability, particularly for sorghum grains.

Total tract NAN digestibility averaged 58.2% and did not differ (P>.10) among corn or sorghum grain hybrid. Streeter et al. (1989f) reported that NAN digestibility decreased as high moisture sorghum replaced corn in a feedlot diet. Rooney and Pflugfelder (1986) suggested that corn protein is more digestible than sorghum protein in the total tract. McCollough and Brent (1972) observed lower CP digestibility for sorghum hybrids compared to corn, but the variation

among diverse sorghum types was small when bird resistant grains were ignored. Recently, large differences in NAN digestibility among four pureline sorghum varieties (Streeter et al., 1989b) and three hybrids (Hibberd et al., 1985) have been reported.

Ruminal Digestion. Chyme flow (liters/d) past the duodenum was greater (P<.05) for corn (48.2) than for red (38.8) and cream (37.5) (Table 5). Differences in particulate passage rate (%/h) were not observed even though corn particles were much larger than sorghum particles. However, differences in ruminal liquid dilution rate (LDR, %/h) were detected; LDR tended to be correlated with particulate passage rate (r=.68; P<.05), but not to duodenal chyme flow (r=.40; P=.18). Corn and het-yel resulted in greater (P<.10) LDR than other sorghum hybrids, with yel greater than (P<.10) cream. Increased chyme flow and LDR for corn may reflect stimulation of mastication and salivation by larger mean particle size (Oltjen et al., 1967). Differences in chyme flow from corn vs high moisture sorghum grain diets have been reported by Streeter et al. (1989f)but, in contrast to this study, replacing corn in that study by high moisture sorghum caused chyme flow to decrease.. Previous studies have concentrated on the interaction of a few common sorghum types (red and hetero-yellow) and reconstitution (Hibberd et al., 1985) or diverse pureline varieties not commonly produced (Streeter et al., 1989b). In those studies, chyme flow differences also have been observed (Hibberd et al., 1985; Streeter et al., 1989b) but differences tended to be related to the bird resistant characteristic. None of the hybrids in this trial were bird resistant.

Variation in starch intake among diets was small (172 g/d), but starch flow to the duodenum differed by 657 g. Starch reaching the duodenum (r=.96; P<.001) and ruminal digestion of starch (r=.96; P<.001) were highly correlated with true OM digestion and comprised about 67% of OM; therefore, OM will not be discussed. Ruminal starch disappearance (g/d) was greater (P<.05) for corn (2,695) than for sorghum hybrids (2,199). Ruminal starch digestibility (%) reflected ruminal starch disappearance with corn (85.8) being greater than (P<.10) cream (73.3), yel (70.7), het-yel (66.9) and red (65.4). Spicer et al. (1986) observed that sorghum grain starch (75.2%) was less digestible in the rumen than either corn (83.7%) or barley starch (87.7%). Waldo (1973) noted that ruminal starch digestibility was slightly greater for corn than for sorghum. However, less variation was noted in ruminal starch digestion with corn than sorghum. Streeter et al. (1989f) observed no difference in ruminal starch digestibility between dry rolled corn and high moisture harvested sorghum. Presumably, high moisture harvesting enhanced digestibility of sorghum starch and reduced differences between grains. Hibberd et al. (1985) reported greater ruminal starch digestibility for a hetero-yellow than for a red sorghum grain hybrid. Ruminal starch digestibility (% of total digestion) was not affected (P>.10) by corn or sorghum grain hybrid, averaging 83.6%. However, in the current study, the rumen tended to (P>.10) be a more important site for starch digestion for corn (92.8% of total tract digestion) than for sorghum hybrids (81.4).

Non-NH_3 N flow past the duodenum averaged 104 g/d and was not affected by diet, but source of this N differed. Microbial N flow at the duodenum tended (P>.10) to be greater for corn (66.1) than for

sorghum grain hybrids (53.4 g/d). Feed plus endogenous N flowing past the duodenum was greater ($P<.05$) for red than for other hybrids and corn. Het-yel, cream and yel had greater ($P<.05$) feed N flow to the small intestine than did corn. Feed N digestibility (%) and escape from ruminal fermentation tended to reflect feed N flow. The greatest ruminal feed N digestibility was observed ($P<.05$) for corn than for sorghum hybrids, with yel, cream and het-yel greater than ($P<.05$) red. Grain N escape of ruminal degradation was lower ($P<.10$) for corn (53.6%) than for sorghum grain hybrids; within sorghum types, red (79.9) was greater than ($P<.10$) het-yel (69.2), cream (66.5) and yel (66.1). Flow of NAN to the duodenum consistently exceeded N intake. Spicer et al. (1986) noted no difference in NAN flow into the abomasum between sorghum grain, corn and barley with NAN flow being greater than N intake for all grains. They found that origin of NAN was affected by grain type, with N being less extensively digested in the rumen from sorghum (27%) than from corn (40.6%) or barley (69.3%). Zinn and Owens (1983a) reported 70.6% of corn N escaped ruminal degradation and in another report (Zinn and Owens, 1983b) that 58 to 73% of corn N escaped ruminal degradation at a DMI of 1.9% of body weight. Hibberd et al. (1985) reported no effect of sorghum grain hybrid on ruminal escape of feed N. Large differences in feed N digestion and escape were noted by Streeter et al. (1989b) for bird resistant sorghum types, but not for endosperm type or color.

Endosperm starch and protein adhere more tightly in sorghum than corn. Interaction of endosperm protein and starch components could reduce ruminal digestibility or alter the site of starch digestion among sorghum grain hybrids (Rooney and Pflugfelder, 1986).

Additionally, diffusion of ruminal fluid into the protein matrix in the peripheral endosperm of sorghum may be retarded (Sullins and Rooney, 1974). Increased escape of sorghum protein from ruminal degradation could affect starch digestion in the small intestine. In our study, escape of feed protein from ruminal degradation was weakly but positively correlated to small intestinal starch digestibility ($r=.34$; $P=.25$). Protein encapsulation of starch may have limited digestion of starch in the small intestine. Russell et al. (1981) reported that high corn intakes increased pancreatic amylase activity in steers. However, at least in rats, increased secretion of amylase appears to be achieved only when diets are adequate in both quantity and quality of protein (Johnson et al., 1977). Amylase activity in the small intestine could be reduced if an insufficient supply of essential amino acids for enzyme synthesis is available for absorption from the small intestine; hence, starch digestion may be reduced. Added dietary protein (soybean meal) has improved total tract starch digestion (Rust et al., 1979; Veira and MacLeod, 1980).

The true efficiency of microbial protein production (g microbial protein /kg OM truly fermented in the rumen) was not affected ($P>.10$) by diet, but tended to be greater for het-yel (20.1) and red (21.3) than for corn (18.2), yel (18.3) and cream (18.5) and was correlated negatively to true ruminal OM digestibility ($r=-.62$; $P<.05$). Microbial protein yield and true ruminal OM digestion also tended to be lower for red and het-yel than for corn, cream and yel. Spicer et al. (1986) reported no effect of grain type on efficiency of microbial protein synthesis. Streeter et al. (1989b) noted no effect of pureline sorghum grain variety on the efficiency of microbial protein production even

though a high tannin variety was included. However, Hibberd et al. (1985) observed differences in the efficiency of microbial protein production between three sorghum grain hybrids, including one high tannin type.

Pre-Cecal Digestion. Starch flow to the cecum (r=.95; P<.001) and pre-cecal starch digestibility (r=.96; P<.001) were strongly correlated to OM flow and digestibility, respectively; hence, the discussion will be limited to starch (Table 6). Yel (808 g/d), red (782) and het-yel (749) had greater (P<.05) starch flow into the cecum than did corn (292). Pre-cecal starch digestibility (%) was greater (P<.05) for corn (90.6) than het-yel (76.2), red (74.8) and yel (74.1). Pre-cecal starch digestibility (% of total tract digestion) was greater (P<.05) for corn (97.9) than red (88.2) and yel (88.0). Streeter et al. (1989b) reported previously that pre-cecal starch digestion was greater for varieties with waxy endosperm than those with normal endosperm. Differences noted herein between corn and certain sorghum grain types may reflect differences in the concentration and continuity of the peripheral endosperm and protein matrix (Rooney and Pflugfelder, 1986).

Non-NH_3 N entering the cecum was greater (P<.05) for red (46.0 g/d) than for all other diets (avg. 37.0 g/d). Although still grown by grain producers, red (white endosperm) may be more representative of the sorghum grain produced in the late 1960's and 1970's with a heavier seed coat and more protein matrix and peripheral endosperm than in the other sorghum hybrids. The greater NAN flow into the cecum and ruminal escape of red sorghum N compared to other diets supports this assumption. Flow of NAN to the cecum suggests that protein from yel, cream and het-yel has only slightly less pre-cecal digestibility than

protein from corn. However, the origin of protein flowing to the cecum was not determined. Grain protein may be less digestible than microbial protein (Neudoerffer et al., 1971). Perhaps less of the protein flowing to the cecum came from corn than sorghum grain diets. Corn or sorghum grain hybrid had no affect on (P>.10) pre-cecal NAN digestibility (% of intake or % of total tract digestion); however, digestibility (%) tended to reflect differences in NAN flow to the cecum. Hibberd et al. (1985) noted no differences among three sorghum grain hybrids on NAN flow to the cecum or pre-cecal digestion. Differences have been noted, however, in NAN flow to the cecum and in pre-cecal digestion among pureline sorghum grain varieties (Streeter et al., 1989b), with major differences being noted due to the bird resistant characteristic.

Digestion in the Intestine. Differences in digestibility in the small intestine were small, but trends were interesting (Table 7). Starch disappearance (g/d) from the small intestine tended to be greater for cream (294), red (311) and het-yel (312) than for corn (145) and yel (110). Because corn had much less starch flowing to the small intestine than sorghum grain hybrids, the corn starch would be expected to contain a greater proportion of less digestible peripheral endosperm than sorghum hybrids did; however, corn starch tended to be more digestible in the small intestine than was sorghum grain starch. Starch flow to the small intestine was correlated positively to starch disappearance in the small intestine (r=.69; P<.01). This compares with a correlation of .77 reported by Owens et al. (1986) which suggests that starch digestion in the small intestine is not limited by animal factors.

Pre-cecal NAN digestibility (%) was correlated positively to starch digestibility (%) in the small intestine ($r=.65$; $P<.05$). This supports the suggestion of Sullins and Rooney (1974) and Harbers and Davis (1974) that the protein matrix of the peripheral endosperm of sorghum may have limited starch availability within the small intestine. Nevertheless, on a weight basis the small intestine tended to be ($P>.10$) a more important site of starch digestion for sorghum grain (cream, het-yel and red) than for corn. However, the importance of a 160 g/d increase in starch disappearance from the small intestine for certain sorghum grains compared to corn is difficult to determine, because total tract starch disappearance was still 232 g/d greater for corn than the average of the sorghum hybrids. Differences in starch disappearance would have favored corn to an even greater extent if compensatory starch fermentation of sorghum grain in the large intestine (Table 8) were ignored. If energetic efficiency were 20% greater for starch digestion in the small intestine than in the rumen (Owens et al., 1986), the decreased total tract digestion would still place sorghum grain at a disadvantage to corn.

Owens et al. (1986) developed a regression equation relating ruminal starch digestibility and starch digestibility in the small intestine (% of intake) to gain to feed ratio (G:F). This equation (G:F=.159*ruminal starch digestibility + .227*starch digestion in the small intestine; $r^2=.60$, $SE_{y.x}=.006$) was combined with flow data from individual animals in this trial to estimate G:F for corn and sorghum grain hybrids (Figure 4). Based on this equation, corn (.147) resulted in greater ($P<.10$) estimated G:F than het-yel (.125), red (.125) and yel (.119), but not greater ($P>.10$) than cream (.137). When G:F from

sorghum hybrids was expressed relative (%) to corn, cream was 93.2% of corn, while het-yel and red were 85.0%, and yel was 81.0% of corn. More extensive processing than rolling might reduce the difference between corn and various sorghum grain hybrids.

Differences in NAN disappearance (g/d) and digestibility (% of flow) within the small intestine among grain sources were small ($P>.10$); NAN disappearance averaged 62.4% of duodenal flow. Tanksley and Knabe (1984) reported that protein from yellow endosperm sorghum was 5% less digestible than corn protein in swine. Digestibility of NAN in the small intestine (% of total tract digestion) was not affected by grain and averaged 116.6%. NAN digestibilities greater than 100% are the result of urea-N recycling to and utilization within the rumen and the large intestine (Kennedy and Milligan, 1980).

Differences in disappearance and digestibility of OM, starch and NAN in the large intestine reflected compensatory starch fermentation; microbial N and OM loss in the feces tended to increase with starch disappearance and to be greater for red and yel than for corn, cream and het-yel (Table 8). Disappearance of starch in the large intestine was correlated positively to starch flow to the cecum ($r=.80$; $P<.01$). This suggests that fermentation in the large intestine increased with starch output; however, a moderate positive correlation between NAN flow to the cecum and starch disappearance from the large intestine ($r=.48$; $P<.10$) may indicate that the endosperm protein matrix no longer limited starch availability. Starch disappearance in the large intestine also was correlated negatively to fecal pH ($r= -.70$; $P<.01$). However, the simple linear regression between starch disappearance in the large intestine and fecal pH in our study was described by the

equation: starch disappearance g/d=-212.2*fecal pH + 1341.7 (r^2=.34; $SE_{y.x}$=58.4).

Rooney and Riggs (1971) and Wagner (1984) have postulated a relationship between starch recovery from wet milling and ruminal starch digestibility. Perhaps a similar relationship exists within the small intestine and possibly the large intestine. Low starch yields from wet milling of sorghum grain may be a result of the thick peripheral endosperm layer (Watson et al., 1955). Wagner (1984) reported that differences in wet milling properties among sorghum grain varieties were related to the proportion of peripheral endosperm. Proteins in corneous endosperm of sorghum grain are composed of protein bodies (kafirin) and a continuous protein matrix (glutelin). Corneous endosperm (measured by hardness) is the result of the protein content, the continuity of the peripheral protein matrix (Rooney and Miller, 1982) and the hybrid (Hoseney et al., 1974). Differences in ruminal, pre-cecal and intestinal starch digestibility among sorghum hybrids likely are influenced by differences in the amount of peripheral endosperm and the continuity of protein matrix as indirectly indicated by the particle size distribution and GMD. Differences in starch and protein digestibility between corn and various sorghum hybrid also may be related to the protein matrix in the peripheral endosperm. Additionally, intermolecular cross links are found in some sorghum prolamine protein fractions that decrease protein extractability; nutritionally, crosslinking may decrease digestibility of both the protein fraction and the starch granules embedded in matrix protein. Protein is more difficult to extract by classical solvent extraction techniques from sorghum than from corn and other cereals (Wall and

Paulis, 1978). Additionally, separation of starch and protein by wet milling is more difficult in sorghum than in corn and the isolated starch generally contains more protein (Wagner, 1984; Rooney and Pflugfelder, 1986).

In summary, sorghum protein from the various hybrids generally was less digestible than that of corn, but starch was affected less. Although corn numerically was drastically more digestible than sorghum grain at all sites of the digestive tract except the large intestine, the cream hybrid was statistically not different from corn at most locations. Predicted feed efficiency was numerically (8%), but not statistically, greater for corn than cream. Yel, which was expected to be the most digestible (starch and N) sorghum hybrid and to be competitive with corn was less digestible than cream. Whether other homozygous yellow endosperm sorghum grains also would be less digestible than corn is uncertain. Perhaps the yellow hybrid utilized in our study would be more digestible if grown in a different environment. Differences between het-yel and cream were large, perhaps being influenced by seed coat color and structure or genetic origin of the yellow endosperm. Red was less digestible than other sorghum hybrids at most locations; however, differences were smaller and more variable than expected. Further study is needed to quantify differences between various homozygous and heterozygous yellow endosperm sorghum grain hybrids.

TABLE 1

DESCRIPTIVE CHARACTERISTICS OF
SORGHUM GRAIN HYBRIDS

Sorghum Hybrid	Seed Coat Color	Endosperm Color	Endosperm Cross
Yellow	yellow	homozygous yellow	yellow x yellow
Cream	white	heterozygous yellow	white x yellow
Hetero-yellow	red	heterozygous yellow	white x yellow
Red	red	homozygous white	white x white

TABLE 2

INGREDIENT COMPOSITION OF EXPERIMENTAL DIETS

Ingredient	% of DM
Grain	85.0
Cottonseed hulls	8.0
Molasses	3.0
Supplement	
Urea	1.20
Dicalcium phosphate	.44
Calcium carbonate	.93
Potassium chloride	.57
Sodium sulfate	.36
Trace mineralized salt	.25
Chromic oxide	.20
Vitamin A premix[a]	.05

[a]2200 IU/kg.

TABLE 3

CHEMICAL COMPOSITION OF FOUR SORGHUM HYBRIDS AND CORN: GRAIN AND COMPLETE MIXED FEEDS (DM BASIS)

Item	Corn	Yellow	Cream	Hetero-Yellow	Red	SE[e]
Grain						
CP, %	10.0^{ab}	9.5^{b}	9.7^{b}	9.6^{b}	10.4^{a}	.18
Starch, %	72.2	78.7	78.3	72.9	79.6	2.65
ADF, %	7.7	7.3	9.6	9.0	8.5	1.49
NaCl soluble nitrogen, % of total N	30.9^{x}	30.8^{x}	27.6^{xy}	21.4^{z}	26.5^{y}	1.26
Pepsin insoluble nitrogen, % of total N	12.4	11.1	12.5	12.2	12.8	.45
Berry size, g/100 berries		2.22^{b}	1.98^{c}	2.53^{a}	2.27^{b}	.038
Berry volume, µl/berry		18.0^{y}	15.5^{z}	20.5^{x}	19.0^{xy}	.71
Density, g/ml		1.24	1.28	1.24	1.20	.032
Feed						
CP, %	12.1^{c}	12.6^{b}	12.5^{b}	12.6^{b}	13.5^{a}	.13
Starch, %	64.7	65.1	62.6	66.4	65.2	2.26
ADF, %	5.4	5.6	6.5	5.7	5.6	.35
Particle size distribution				%		
5,657 µm, %	76.0^{a}	.2^{b}	.2^{b}	.2^{b}	.2^{b}	.38
2,828 µm, %	22.0^{w}	3.4^{yz}	1.8^{z}	7.1^{x}	4.6^{y}	.74
1,414 µm, %	1.4^{z}	75.8^{x}	65.2^{y}	79.8^{x}	64.0^{x}	3.58
707 µm, %	.2^{c}	9.3^{b}	13.0^{a}	7.3^{b}	15.2^{a}	.81
354 µm, %	.1	4.3	7.8	1.8	5.6	1.98
177 µm, %	.2^{z}	7.0^{xy}	11.9^{x}	3.8^{yz}	10.6^{x}	2.04
Geometric mean diameter(GMD), µm	4,692^{w}	1110^{xy}	928^{z}	1275^{x}	982^{yz}	57.2

^{abc}Means in the same row with different superscripts differ ($P<.05$).

^{e}Two observations/mean for grain and five observations/mean for feed.

^{wxyz}Means in the same row with different superscripts differ ($P<.10$).

TABLE 4

COMPARISON OF TOTAL TRACT DIGESTION OF FOUR SORGHUM GRAIN HYBRIDS WITH CORN

Item	Corn	Yellow	Cream	Hetero-Yellow	Red	SE
Fecal output, kg/d	4,685^{y}	5,869^{x}	5,300^{xy}	6,070^{x}	6,258^{x}	399.0
Fecal pH	5.84	5.07	5.32	5.16	5.30	.184
Feces, g/d						
OM	1,168^{b}	1,494^{a}	1,284^{ab}	1,525^{a}	1,496^{a}	98.7
Starch	232^{z}	488^{xy}	356^{yz}	541^{x}	491^{xy}	71.2
Total N	36.8^{z}	41.4^{yz}	40.0^{yz}	41.9^{y}	47.1^{x}	2.02
Non-NH_3 N	36.0^{z}	41.0^{yz}	39.7^{yz}	41.5^{y}	46.7^{x}	2.00
Total tract digestibility, %						
OM	74.7^{x}	67.3^{yz}	72.0^{xy}	66.6^{z}	67.3^{yz}	2.12
Starch	92.5^{a}	84.3^{b}	87.9^{ab}	82.9^{b}	84.3^{b}	2.28
Total N	60.2	57.7	58.8	57.2	54.7	2.18
Non-NH_3 N	61.0	58.1	59.1	57.6	55.1	2.15
Total Tract Disappearance, g/d						
OM	3,460^{x}	3,107^{yz}	3,341^{xy}	3,083^{z}	3,085^{z}	100.7
Starch	2,900^{a}	2,659^{b}	2,687^{b}	2,673^{b}	2,653^{b}	71.2
N	57.0	56.4	57.3	56.1	56.8	2.48
Non-NH_3 N	57.8	56.8	57.6	56.5	57.2	2.45

^{abc}Means in the same row with different superscripts differ ($P<.05$).

^{xyz}Means in the same row with different superscripts differ ($P<.10$).

TABLE 5

COMPARISON OF RUMINAL DIGESTION OF FOUR SORGHUM GRAIN HYBRIDS WITH CORN

Item	Corn	Yellow	Cream	Hetero-Yellow	Red	SE
Intake, g/d						
OM	4,629	4,601	4,625	4,608	4,582	
Starch	3,132	3,147	3,042	3,214	3,144	
Total feed N	93.8	97.7	97.3	98.0	103.9	
Non-urea feed N	67.1	71.1	70.5	71.3	77.3	
Ruminal pH	5.97	5.86	5.83	5.94	5.92	.071
Ruminal NH_3 N, mg/dl	7.60	10.02	7.81	9.45	8.36	1.745
Duodenal chyme						
pH	2.36	2.38	2.40	2.49	2.39	.073
flow, liters/d	48.2^{a}	43.6^{ab}	37.5^{b}	42.0^{ab}	38.8^{b}	2.62
Particulate rate of passage, %/h	4.05	4.01	3.96	4.31	3.69	.563
Liquid dilution rate, %/h	5.10^{x}	4.24^{y}	3.48^{z}	5.01^{x}	4.04^{yz}	.280
Entering the duodenum, g/d						
Total OM	$1,866^{y}$	$2,400^{y}$	$2,315^{xy}$	$2,612^{x}$	$2,792^{y}$	197.6
Microbial OM	942	765	775	754	752	76.0
Non microbial OM	924^{y}	$1,636^{x}$	$1,540^{x}$	$1,858^{x}$	$2,040^{x}$	205.9
Starch	437^{b}	918^{a}	813^{ab}	$1,061^{a}$	$1,094^{a}$	149.3
Total N	104	104	104	105	118	7.0
Non-NH_3 N	101	100	101	102	115	6.8
Microbial N	66.1	53.7	54.4	52.9	52.8	5.34
Feed N	35.1^{c}	46.7^{b}	46.8^{b}	49.3^{b}	61.9^{a}	2.59
Ruminal disappearance, g/d						
Starch	$2,695^{a}$	$2,229^{b}$	$2,230^{b}$	$2,153^{b}$	$2,050^{b}$	149.6
Ruminal digestibility, %						
OM (true)	80.0^{x}	64.3^{yz}	66.9^{y}	59.6^{yz}	55.7^{z}	4.43
Starch	85.8^{x}	70.7^{y}	73.3^{y}	66.9^{y}	65.4^{y}	4.64
Total feed N	61.9^{a}	52.0^{b}	52.0^{b}	49.7^{b}	40.6^{c}	2.68
Non-urea feed N	46.4^{x}	33.9^{y}	33.5^{y}	30.8^{y}	20.1^{z}	3.72
Ruminal escape of feed N, %	53.6^{z}	66.1^{y}	66.5^{y}	69.2^{y}	79.9^{x}	3.72
True efficiency of microbial protein production, g MP/kg OM truly fermented	18.2	18.3	18.5	20.1	21.3	2.00
Ruminal digestibility, % of total tract digestion						
Non-microbial OM	107.4^{a}	94.8^{ab}	93.3^{ab}	89.3^{b}	83.6^{b}	5.70
Starch	92.8	83.3	83.6	80.7	77.8	4.63

^{abc}Means in the same row with different superscripts differ ($P<.05$).

^{xyz}Means in the same row with different superscripts differ ($P<.10$).

TABLE 6

COMPARISON OF PRE-CECAL DIGESTION OF FOUR SORGHUM GRAIN HYBRIDS WITH CORN

Item	Corn	Yellow	Cream	Hetero-Yellow	Red	SE
Leaving ileum, g/d						
Chyme, liters	10.4	11.0	9.7	10.4	11.4	.87
OM	1,191^{c}	1,868^{a}	1,426^{bc}	1,689^{ab}	1,828^{ab}	142.2
Starch	292^{b}	808^{a}	519^{ab}	749^{a}	782^{a}	113.3
Total N	35.4^{b}	40.4^{b}	36.8^{b}	37.6^{b}	46.5^{a}	1.98
Non-NH_3 N	34.8^{b}	39.9^{b}	36.2^{b}	36.9^{b}	46.0^{a}	1.95
Pre-cecal digestibility, %						
OM	74.2^{x}	59.7^{z}	68.8^{xy}	62.9^{yz}	59.9^{z}	3.08
Starch	90.6^{a}	74.1^{b}	82.5^{ab}	76.2^{b}	74.8^{b}	3.67
Total N	61.8	58.7	62.1	61.6	55.3	2.17
Non-NH_3 N	62.4	59.3	62.6	62.2	55.8	2.13
Pre-cecal digestibility, % of total tract digestion						
OM	99.3^{x}	88.4^{z}	95.4^{x}	94.2^{xz}	88.5^{z}	2.72
Starch	97.0^{a}	88.0^{b}	93.4^{ab}	91.7^{ab}	88.2^{b}	2.79
Total N	103.5	102.0	106.2	107.8	101.4	2.04
Non-NH_3 N	103.2	102.2	106.5	108.2	101.7	2.06

^{abc}Means in the same row with different superscripts differ ($P<.05$).

^{xyz}Means in the same row with different superscripts differ ($P<.10$).

TABLE 7

COMPARISON OF DIGESTION OF FOUR SORGHUM GRAIN HYBRIDS WITH CORN IN THE SMALL INTESTINE

Item	Corn	Yellow	Cream	Hetero-Yellow	Red	SE
Disappearance in the small intestine, g/d						
OM	675	532	888	923	964	193.7
Starch	145	110	294	312	311	139.8
Total N	68.9	63.2	67.2	67.7	71.3	5.85
Non-NH_3 N	66.4	60.5	65.0	65.2	68.7	5.77
Digestibility in the small intestine:						
% of entry						
OM	37.2	19.2	35.1	34.7	32.1	6.87
Starch	39.7	12.0	25.1	28.8	24.6	14.75
Total N	65.9	60.0	64.0	64.2	60.1	1.88
Non-NH_3 N	65.4	59.8	63.5	63.7	59.5	1.95
% of intake						
OM	14.6	11.4	18.6	19.7	20.6	4.22
Starch	4.8	3.4	9.2	9.3	9.5	4.46
Total N	74.5	64.9	68.7	69.0	68.4	6.08
Non-NH_3 N	71.8	62.1	66.4	66.5	65.9	6.01
% of total tract digestion						
OM	20.0	18.0	25.4	29.9	29.7	6.45
Starch	5.1	4.6	9.8	11.0	10.4	5.32
Total N	133.1	114.4	117.1	120.9	124.9	12.55
Non-NH_3 N	126.3	108.6	112.5	115.8	119.6	11.96

TABLE 8

COMPARISON OF DIGESTION OF FOUR SORGHUM GRAIN HYBRIDS WITH CORN IN THE LARGE INTESTINE

Item	Corn	Yellow	Cream	Hetero-Yellow	Red	SE
Disappearance in the large intestine, g/d						
OM	23z	374x	142yz	164yz	331xy	82.6
Starch	60b	320a	163ab	208ab	291a	70.5
Non-NH_3 N	-1.1	-1.1	-3.4	-4.5	-.8	1.18
Digestibility in the large intestine:						
% of entry						
OM	1.7z	20.0x	9.7yz	9.0yz	17.7xy	4.00
Starch	22.8	38.8	31.5	29.8	36.6	8.70
Non-NH_3 N	-2.1^{yz}	-3.6^{yz}	-9.0^{xy}	-12.4^{x}	-1.8^{z}	2.77
% of intake						
OM	.5z	8.1x	3.1yz	3.7xyz	7.4xy	1.81
Starch	1.9b	10.2a	5.4ab	6.6 ab	9.5a	2.27
Non-NH_3 N	-1.4	-1.2	-3.6	-4.7	-.7	1.14
% of total tract digestion						
OM	.7y	11.6x	4.6y	5.8xy	11.4x	2.72
Starch	2.1b	12.0a	6.6ab	8.3ab	11.8a	2.79
Non-NH_3 N	-3.2	-2.2	-6.5	-8.2	-1.7	2.06

^{abc}Means in the same row with different superscripts differ ($P<.05$).

^{xyz}Means in the same row with different superscripts differ ($P<.10$).

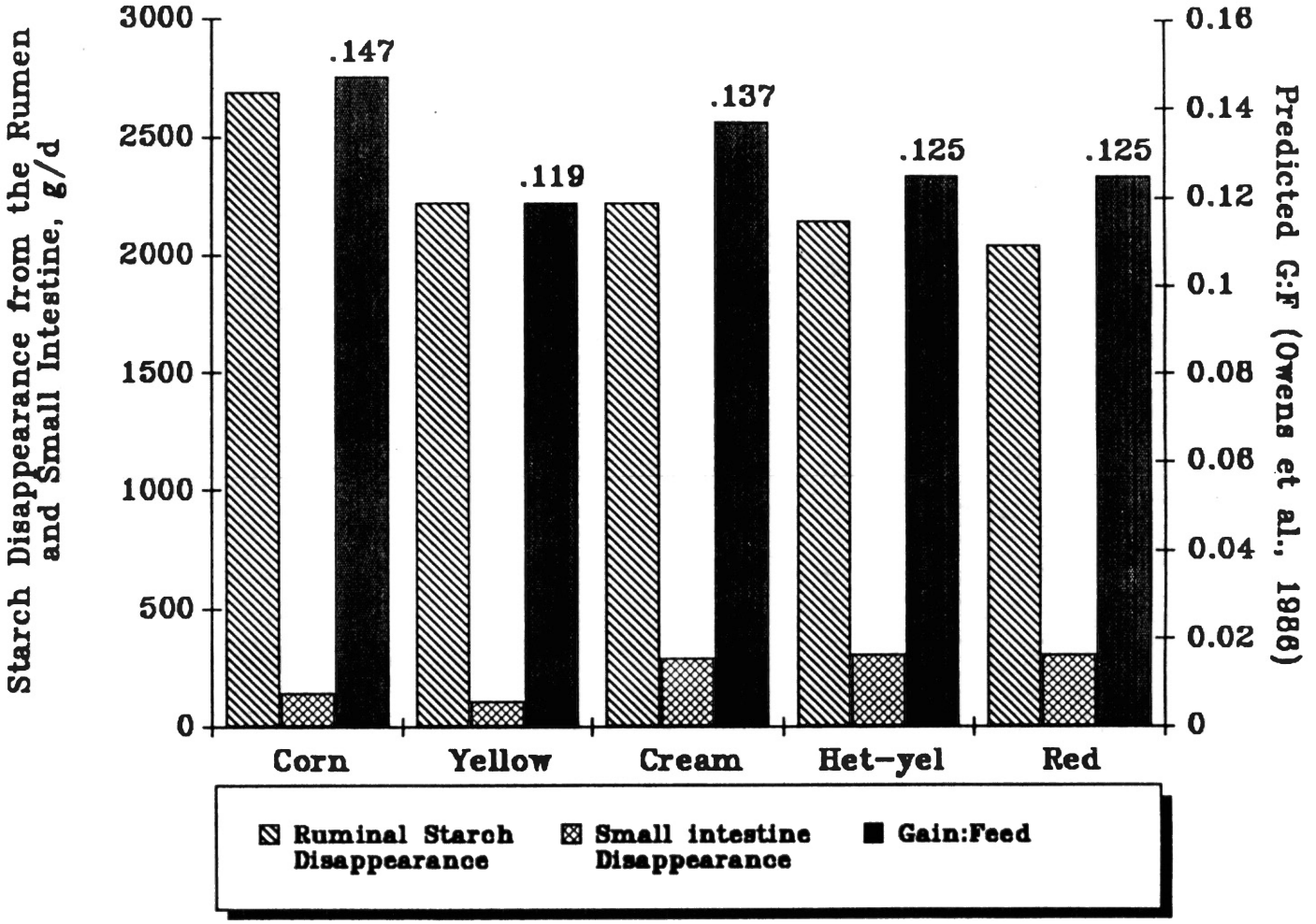

Figure 4. Starch Disappearance (g/d) from the Rumen and Small Intestine and Predicted Gain:Feed (G:F=.159*Ruminal Starch Digestibility + .227*Starch Digestion in the Small Intestine) for Sorghum Grain Hybrids and Corn

CHAPTER V

THE EFFECT OF SORGHUM GRAIN HYBRID AND CORN ON STARCH AND DRY MATTER DIGESTION IN VITRO[1]

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ABSTRACT

Studies of ruminal dry matter disappearance in vitro (IVDMD) and gas production in vitro (GP), involving amyloglucosidase and yeast, were conducted to compare eight divergent current sorghum grain hybrids and corn. Chemical and physical characteristics of the grains also were described. Sorghums included two yellow (Y1 and Y2), two cream (C1 and C2), two hetero-yellow (HY1 and HY2), one red (R) and one bird resistant (BR) hybrids. Corn (29.7%) contained more ($P<0.05$) sodium chloride soluble nitrogen (NaCl-N) than other grains except Y1 (26.7%). BR contained more pepsin insoluble nitrogen and less NaCl-N, and had smaller berries of greater density ($P<0.05$) than other grains. BR

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(26.9%) had lower (P<0.05) and corn (51.8%) had greater (P<0.05) IVDMD than other sorghum hybrids. Yellow hybrids were 1.9% more digestible than cream hybrids and 6.2% more digestible than hetero-yellow hybrids. Y1 (42.2), Y2 (42.2), C1 (42.0) and HY1 (41.9) had greater (P<0.05) IVDMD than HY2 (37.2), with C2 (40.8) being intermediate (P>0.05). BR and HY1 had greater (P<0.05) and corn (253.3) had less (P<0.05) 12-hour GP than other grains. The estimated first order rate constant for starch digestion was highest (P<0.05) for BR and lowest (P<0.05) for corn. The rate of starch degradation among sorghum hybrids of common endosperm and seed coat color differed, with C2, HY1 and Y1 tending to have a greater rate of GP than R, while HY2, C1 and Y2 tended to have a lower rate of GP than R. When hybrids with a yellow endosperm were averaged within endosperm and seed coat color, no advantage was noted for homozygous or heterozygous yellow endosperm. However, sorghum grain with a yellow endosperm (homozygous or heterozygous) tended to have greater starch availability than R, and parental varieties altered starch availability within endosperm types.

Introduction

Corn and sorghum grain are widely used in the feedlot industry. World wide, sorghum is the third most prevalent grain. Sorghum often is discriminated against by cattle feeders because of variable quality and lower efficiency compared to corn (McCollough et al., 1972).

Although little information exists, Rooney and Pflugfelder (1986) suggested sorghum grain with a yellow endosperm may be more digestible than sorghum with a non-yellow endosperm. Goldy et al. (1988) noted slightly lower gains with yellow endosperm sorghum than corn, but

Brethour (1987) observed better feed utilization for a homozygous yellow endosperm sorghum grain than for corn. While untested, sorghum breeders generally believe that hybrids created from different parental varieties should differ in digestibility, even though hybrids may have a common endosperm and(or) seed coat color.

The relationships between endosperm type and color and physical and chemical characteristics and digestibility in sorghum is unclear. Endosperm type and color may alter ruminal fermentation and starch availability. The objective of the study, therefore, was to evaluate differences between eight sorghum grain hybrids and corn in physical and chemical structure, ruminal dry matter disappearance in vitro (IVDMD) and enzymatic starch availability in vitro (GP).

Materials and Methods

Eight genetically unique sorghum grain hybrids were grown under dryland conditions in southeast Kansas, USA during the summer of 1986. Corn was purchased commercially. Descriptive characteristics of the sorghum grains are denoted in Table 9. Sorghum hybrids included two pure yellow (Y1 and Y2; homozygous yellow endosperm, yellow seed coat), two cream (C1 and C2; heterozygous yellow endosperm, white seed coat), two hetero-yellow (HY1 and HY2; heterozygous yellow endosperm, red seed coat), one red (R; homozygous white endosperm, red seed coat) and one brown high tannin bird resistant (BR; homozygous white endosperm, brown seed coat) sorghum grains.

Grains were characterized by the average weight of 100 randomly selected berries, the average volume of toluene displaced by 100 berries and the resulting density. Grains were ground through a .4-mm

screen before chemical characterization. Crude protein was determined by the Kjeldahl procedure (AOAC, 1975), and starch was measured as alpha-linked glucose polymers (MacRae and Armstrong, 1968). Condensed tannin was determined by the vanillin-HCl procedure (Burns, 1971) as modified by Price et al. (1978) and is reported in catechin equivalents/gram of dry matter (CE). Grain samples were further analyzed for pepsin insoluble nitrogen (PIN, Goering and Van Soest, 1970) and sodium chloride soluble nitrogen (NaCl-N; Waldo and Goering, 1979).

Dry matter disappearance in vitro (IVDMD) was determined using grain samples previously ground through a 1-mm screen. Ruminal fluid was obtained from a steer consuming a high grain diet, strained twice through four layers of cheesecloth and mixed with pre-warmed McDougall's buffer (McDougall, 1948). Thirty milliliters of inoculant (22 ml buffer:8 ml ruminal fluid) were placed in pre-weighed 50 ml centrifuge tubes containing 0.4 g of grain dry matter. After an 18-h incubation at 39^{o} C, tubes were centrifuged, decanted and dried for 48 h in an oven at 60^{o} C.

Gas production in vitro (GP; Sandstedt et al., 1962) of the grains was measured to estimate differences in starch availability to enzymatic degradation. Grains (0.4 g) were incubated (39^{o} C) for 24 h with commercial baker's yeast (0.5 g) and an amyloglucosidase (Sigma Chemical Co., from Rhizopus mold, E.C. 3.2.1.3) solution (10 ml, 0.1% W/V) in a 20 ml culture tube (Hibberd et al., 1982a). GP was measured by displacement of the plunger of a gas tight syringe. Measurements were recorded hourly for 8 h and at 10, 12 and 24 h. Data were analyzed to determine differences in extent of starch digestion by

measuring the total gas produced at 6 (GP6), 8 (GP8), 10 (GP10), 12 (GP12) and 24 (GP24) h, expressed as ml of CO_2/g of grain starch. The rate of starch disappearance (k_1) was estimated by fitting the single pool kinetic model described by Streeter et al. (1989a) to our GP curves. Rates of gas production were described by the model, CO_2 (ml/g starch) = $CF*(1-e^{(k1*t)})$, where CF is a factor to convert g of starch to ml of CO_2 and k1 is the estimated first order rate constant of starch disappearance. Theoretical conversion of starch to CO_2 (315.9), assuming ethanol fermentation by bakers yeast, was approached in this study (309.4 $\pm$ 3.95). However, when the theoretical conversion was utilized the residual sum of squares was increased; hence, k1 and CF were estimated for each grain within each of four runs, utilizing the iterative non-linear procedure of SAS (1988).

Statistical Analysis

Data from IVDMD and GP can be described by the following model: $Y_{ijk} = \mu + R_i + G_j + E_{ijk}$, where Y_{ijk} is 18-h IVDMD, GP or k1, R is the run and G is the grain source. Random errors, E_{ijk}, were specific to each observation. The components μ, R_i, and G_j were treated as fixed effects of all records of run i and grain j. Random errors, E_{ijk}, were specific to each observation. Estimated differences among least squares means were detected using protected least significant differences (Steel and Torrie, 1980).

Results and Discussion

Chemical Composition

Sorghum grain endosperm and seed coat color did not consistently influence starch content (Table 10). Sorghum grains Y1, R and C1 contained more starch ($P<0.05$) than HY1, BR and corn, with C2, HY2 and Y2 ($P>0.05$) being intermediate. Crude protein (CP) ranged from 10.5% (Y2) to 9.5% (Y1). Grains Y2, R, HY2 and corn contained more CP ($P<0.05$) than Y1, with other grains being intermediate. NaCl-N ranged from 29.7% of N for corn to 13.0% for BR. Corn and Y1 (26.7%) contained a greater ($P<0.05$) proportion of NaCl-N than HY1 (19.6%), with BR (13.0%) being lower ($P<0.05$) than other grains. Although other chemical constituents were not consistently altered by sorghum type, BR contained more PIN ($P<0.05$) than other grains. Condensed tannin present in BR probably bind grain protein reducing pepsin digestibility. Hibberd et al. (1982a) and Streeter et al. (1989a) reported more PIN for BR sorghum grains. Red also tended to contain more PIN than grains with a yellow endosperm (Y1, Y2, C1, C2, HY1 and HY2) and corn being statistically greater ($P<0.05$) only for C2. Rooney and Pflugfelder (1986) reported sorghum grain to have slightly greater starch and N and less ether extract than corn. Hibberd et al. (1982a) reported wide variation in N and starch content among nine sorghum grain varieties as well as differences in the same varieties grown in different years. Wall and Paulis (1970) suggested N and starch content of sorghum grain may be dramatically influenced by rainfall, environmental temperature and environmental-hybrid interactions.

Physical Characteristics

Hybrids C2 (2.61) and HY1 (2.53) had larger ($P<0.05$) berries (g/100 berries) than other sorghum grain. Red (2.27), Y1 (2.22), HY2

(2.18) and Y2 (2.13) had larger ($P<0.05$) berries than C2 (1.98) and BR (1.64). Berry volume tended to reflect berry size ($r=.80$; $P<0.05$), with HY1 (20.5 μl), C2 (20.0) and R (19.0) having larger berries ($P<0.05$) than Y2 (16.5), C1 (15.5) and BR 12.0). Other sorghum grain hybrids had intermediate ($P<0.05$) berry volume. Berry density was greater ($P<0.05$) for BR (1.38 g/ml) and C2 (1.32) than for R (1.20), with others being intermediate. Density of sorghum types was less variable than berry size and volume and may reflect relatively small differences in starch and N content. Greater density may reflect more peripheral and less floury endosperm. Scanning electron microscopy (SEM) conducted by Hoseney et al. (1974) has indicated that floury endosperm contains large inter-granular air spaces, while peripheral endosperm has a tightly packed granular alignment with no air spaces between starch granules. Large berries have previously been thought to be more digestible than small berries, perhaps because they may be easier to process consistently rather than due to inherent characteristics of a given sorghum hybrid and had been thought to contain more starch and less protein than smaller berries (Hibberd, 1982). Yet in our study starch content was negatively correlated to berry size ($r=-0.86$; $P<0.01$) and volume ($r=0.83$; $P<0.05$) but positively correlated to density ($r=0.73$; $P<0.05$) while %N was positively correlated to berry volume ($r=0.66$; $P<0.10$). Berry size ($r=0.27$; $P<0.40$) and density ($r=-0.58$; $P<0.15$) were only weakly correlated to N content. These data should not be interpreted to mean that within a hybrid, where less variation in peripheral and floury endosperm content might be expected, larger berries would necessarily contain less starch and more protein than smaller berries.

Dry Matter Disappearance In Vitro

IVDMD was lower (P<0.05) for BR (26.93%) and greater (P<0.05) for corn (51.83) than for other sorghum grain hybrids. Among remaining sorghum types, R (43.94), Y1 (42.19), Y2 (42.16), C1 (41.95) and HY1 (41.89) were more (P<0.05) digestible than HY2 (37.18), with C2 (40.81) being intermediate. Hibberd et al. (1982a) reported that corn had a greater IVDMD than pureline sorghum grain types with a normal endosperm. Pureline BR sorghum types with a normal endosperm have been noted to be less digestible in vitro than other sorghum types (Hibberd et al., 1982a; Streeter et al., 1989a). Sorghum hybrids with a homozygous yellow endosperm (Y1 and Y2) were 1.9% more digestible than cream hybrids (C1 and C2) and 6.2% more digestible than hetero-yellow hybrids (HY1 and HY2). Rooney and Pflugfelder (1986) noted sorghum with a yellow endosperm was more digestible than grain with a non-yellow endosperm; however, in our study R (homozygous white endosperm) tended to have a greater IVDMD than hybrids with a yellow endosperm. Perhaps yellow endosperm hybrids have greater enzymatic starch digestibility in the small intestine which should result in more efficient gains (Black, 1971).

Gas Production In Vitro

Total GP at 6 (r=0.63; P<0.01), 8 (r=.074; P<0.01), 10 (r=0.80; P<0.01) and 12 (r=0.74; P<0.01) h was highly correlated to gas production at 24 h but, the ranking of grains differed some between 6, 8, 10, 12 and 24 h (Table 12). Hence, the discussion will include 6 (GP6), 12 (GP12) and 24 (GP24) h values. GP6 was greater (P<0.05) for BR (236.0 ml CO_2/g of starch) and less (P<0.05) for corn (178.5) than

for other grains, and Y1, C2 and HY1 were greater ($P<0.05$) than HY2, C1 and Y1. GP12 was greater for C2 (282.5) than ($P<0.05$) HY2 (271.1), with Y1, Y2 and C1 intermediate. After 12 h of incubation, sorghums with a yellow endosperm averaged 1.9% more CO_2 than R and 10% more than corn. Individual hybrids were even more superior to R and corn. GP24 differences were small, with HY1 (315.1) and BR (308.7) greater ($P<0.05$) than C1 (294.0), R (293.5) and corn (292.9). Other than HY1 homozygous or heterozygous yellow endosperm sorghum tended to be intermediate between BR and R. Hibberd et al. (1982b) studied isolated starch from several pureline sorghum and corn varieties. Starch from corn produced less gas and starch from BR sorghum produced more gas than several normal endosperm varieties. Although total tract starch digestibility was reduced, Streeter et al. (1989b) reported greater ruminal starch digestibility for two BR sorghum varieties than two non-BR varieties.

Sorghum grain usually has been reported to have a much greater proportion of peripheral endosperm cells than corn (Rooney and Pflugfelder, 1986). Because peripheral endosperm cells normally have a high protein content and resist both physical and enzymatic degradation (Rooney and Pflugfelder, 1986), one would expect sorghum grain to be less digestible than corn; moreover, sorghum grains which contain more peripheral endosperm should be less digestible than those with less peripheral endosperm. However, our GP results suggest that starch from sorghum grain, when ground through a .4-mm screen, may be more available to enzymatic degradation than is corn starch. Our IVDMD data, on the other hand suggested corn to be somewhat more digestible. Differences noted herein between IVDMD and GP may be influenced by

differences in grain particle size. The smaller screen used to grind grain for measuring GP may increase the surface area sufficiently to reduce potential limitations on starch digestion caused by protein encapsulation.

Leach and Schoch (1961) have suggested that starch in sorghum is hydrolyzed by bacterial alpha amylase to a greater extent than in corn. If starch granules in sorghum are hydrated more rapidly than in corn, more rapid diffusion of starch degrading enzymes into the starch granule may occur. Leach and Schoch (1961) hypothesized that starch granules which have a greater susceptibility to alpha amylase may contain pores or a coarse sponge-like structure, with openings of sufficient size to reduce stearic hindrance of enzymatic attack.

Changes noted in the rank order of the grains with time indicate alterations in the rate of CO_2 production over time. To address this concern, percent change in GP between 6, 8, 10, 12 and 24 h was calculated from least squares means. In an attempt to simplify results, Y1 and Y2 were combined (Y). Likewise C1 and C2 (C) and HY1 and HY2 (HY) were averaged. BR tended to have a smaller and corn a larger change in GP between time intervals than did other grains. Moreover, sorghums with a yellow endosperm (Y, HY and C) tended to have larger changes in GP than R. These results indicate that BR sorghum grain is digested at a faster rate early in the incubation period and at a slower rate later than are other grains. While corn displayed the reverse pattern. Sorghum hybrids with a yellow endosperm (Y1, Y2, HY1, HY2, C1 and C2) appeared to be degraded more like corn than BR, while R was intermediate between BR and the yellow hybrids. The potential importance of differential rates of starch hydration and degradation

may be related to differences in site and extent of starch digestion and ultimately the efficiency of energy utilization by ruminants (Black, 1971). Therefore, comparisons of GP among sorghum hybrids and corn may provide valuable information about the rate and(or) extent of starch availability to enzymatic attack.

Rate Constants for GP

Rate constants (k1) were strongly correlated to total GP at 1 ($r=0.64$; $P<0.01$), 2 ($r=0.60$; $P<0.01$) and 3 h ($r=0.55$; $P<0.01$). The strength of the correlation of k1 and GP decreased with time, eventually becoming negative at 24 h ($r=-0.33$; $P<.11$). A decreasing correlation between k1 and GP over time may indicate that factors other than the rate of enzymatic glucose release limit GP.

The CF was strongly correlated to GP at 24 ($r=0.98$; $P<0.01$), 12 ($r=0.80$; $P<0.01$), 10 ($r=0.84$; $P<0.01$ and 8 h ($r=0.76$; $P<0.01$). The strength of the correlation increased with time, perhaps because as more starch is degraded and utilized for CO_2, GP should more closely approach or equal the theoretical CF (315.9). If, however, starch is utilized for yeast growth the CF should be lower than the theoretical value, but still highly related to GP24.

The CF for HY1 (327.7) was greater ($P<0.05$) than for other grains and above the theoretical value, which may indicate that starch was underestimated. The CF for Y2 (314.0) and BR (313.6) were greater than ($P<0.05$) for corn (299.3), with C2 (310.6), Y1 (306.3), HY2 (305.2) and R (302.8) being intermediate ($P>0.05$). Variation among CF for grains may indicate differences in the efficiency of yeast fermentation or in estimation of starch supplied to the system.

Estimates of k1 (Table 12) ranged from 0.156 (corn) to .228 %/h (BR), with BR resulting in a greater ($P<0.05$) and corn resulting in a lower ($P<0.05$) k1 than other grains. Y1 (0.199) and C2 (0.197) had a greater ($P<0.05$) k1 than HY2 (0.183), C1 (0.182), HY1 (.174) and Y2 (0.170), while R (0.1920) was intermediate; however, HY2 and C1 were greater than ($P<0.05$) Y2. Streeter et al. (1989a) noted that two pureline BR varieties, one normal and waxy endosperm, had greater rates of starch degradation than a non-BR normal endosperm variety. Perhaps, BR sorghum grains are degraded at a faster rate due to denaturation by condensed tannin of a portion of the protein matrix that encapsulates the starch granules in the peripheral endosperm. Generally, condensed tannins are viewed as inhibitory to digestive enzymes (Tagari et al., 1969; McLeod, 1974); however, condensed tannins can have a stimulatory effect on tryptic digestion (Mole and Waterman, 1982). It is unclear if condensed tannin could have a similar stimulatory effect on amyloglucosidase.

Protein digestibility may play an important role in starch degradation in vitro and in vivo. Seckinger and Wolf (1973), based on SEM, suggested protein encapsulation of starch granules in sorghum may limit starch degradation. The encapsulation of starch granule by protein matrix appears to be related to the amount of peripheral endosperm. Hoseney et al. (1974) observed a continuous protein matrix encapsulating the starch granules in the peripheral endosperm, with a less continuous matrix existing in the floury endosperm. Additionally, starch granules in the floury endosperm of sorghum grain appeared to be covered with a thin layer of protein which is not present in corn. Tanksly and Knabe (1984) reviewed several swine studies concluding that

the protein in sorghum grains with a yellow endosperm was 5% less digestible than that in corn. Rooney and Riggs (1971) postulated a relationship between starch recovery during wet milling, limited by the peripheral endosperm layer (Watson et al., 1955), and ruminal starch digestibility. A similar relationship may explain differences observed among our sorghum hybrids. Norris and Rooney (1970) reported the peripheral endosperm content of sorghum grain hybrids was intermediate between that observed for the parental varieties. Therefore, difference between hybrids with a common endosperm and(or) seed coat color may result from variation in the peripheral endosperm content originating from the parental varieties of a hybrid.

TABLE 9

DESCRIPTIVE CHARACTERISTICS OF
SORGHUM GRAIN HYBRIDS

Grain Source	Seed Coat Color	Endosperm Color	Endosperm Cross	Testa Layer[a]
Y1 and Y2	yellow	yellow	yellow x yellow	absent
C1 and C2	white	yellow	white x yellow	absent
HY1 and HY2	red	yellow	white x yellow	absent
R	red	white	white x white	absent
BR	brown	white	white x white	present

[a] Presence of testa layer indicative of high tannin content and bird resistance.

TABLE 10

CHEMICAL COMPOSITION OF SORGHUM GRAIN HYBRIDS AND CORN (DRY MATTER BASIS)

Item	Starch	Crude protein	NaCl-N[v]	PIN[w]	Tannin[x]	ADF[y]
Grain						
Corn	72.6^{e}	10.0^{bc}	29.7^{a}	12.4^{bc}	0.03^{b}	7.7
Y1	79.9^{a}	9.5^{d}	26.7^{ab}	12.8^{b}	0.00^{b}	8.5
Y2	76.1^{bcd}	10.5^{a}	23.2^{bc}	12.5^{bc}	0.00^{b}	6.9
C1	78.4^{ab}	9.7^{cd}	23.6^{bc}	12.5^{bc}	0.00^{b}	9.6
C2	77.4^{abc}	9.7^{cd}	22.0^{bc}	10.8^{c}	0.07^{b}	6.1
HY1	74.4^{cde}	9.6^{cd}	19.61^{c}	12.2^{bc}	0.08^{b}	9.0
HY2	76.8^{abcd}	10.3^{ab}	22.3^{b}	11.5^{bc}	0.08^{b}	11.2
R	79.8^{a}	10.4^{ab}	23.6^{bc}	12.8^{b}	0.02^{b}	8.5
BR	74.0^{de}	9.7^{cd}	13.0^{d}	24.6^{a}	1.03^{a}	13.9
SE[z]	1.06	0.13	1.54	0.60	0.093	1.70

^{abcde}Means in the same column with different superscripts differ ($P<0.05$).

[v]Sodium chloride soluble protein, % of crude protein.

[w]Pepsin insoluble nitrogen, % of crude protein nitrogen.

[x]Catechin equivalents/g dry matter.

[y]Acid detergent fiber.

[z]Standard error based on 2 observations per mean.

TABLE 11

PHYSICAL CHARACTERISTICS OF
SORGHUM GRAIN HYBRIDS

Item	Berry size g/100 berries	Berry volume µl/berry	Density g/ml
Grain			
Y1	2.22^{bc}	18.0^{bc}	1.24^{bc}
Y2	2.13^{c}	16.5^{cd}	1.29^{abc}
C1	1.98^{d}	15.5^{d}	1.28^{abc}
C2	2.61^{a}	20.0^{a}	1.32^{ab}
HY1	2.52^{a}	20.5^{a}	1.24^{bc}
HY2	2.18^{bc}	17.5^{bc}	1.25^{bc}
R	2.27^{b}	19.0^{ab}	1.20^{c}
BR	1.64^{e}	12.0^{e}	1.38^{a}
SE[x]	0.038	0.59	0.031

^{abcde}Means in the same column with different superscripts differ ($P<0.05$).

[x]Standard error based on 2 observations per mean.

TABLE 12

DRY MATTER DISAPPEARANCE AND GAS PRODUCTION IN VITRO OF SORGHUM GRAIN HYBRIDS AND CORN

Item	18 h IVDMD	GP, ml gas/g of grain starch 6 h	10 h	12 h	24 h	CF[x]	k1, %/h[y]
Grain							
Corn	51.83^{a}	178.5^{e}	237.3^{e}	253.3^{e}	292.9^{c}	299.3^{c}	0.141^{e}
Y1	42.19^{b}	213.0^{b}	268.1^{cd}	279.1^{bc}	299.5^{bc}	306.3^{bc}	0.186^{bc}
Y2	42.16^{b}	200.0^{d}	262.1^{cd}	275.7^{bcd}	303.9^{abc}	314.0^{b}	0.168^{d}
C1	41.95^{b}	200.7^{d}	260.9^{d}	272.2^{cd}	294.0^{c}	305.1^{bc}	0.169^{d}
C2	40.81^{bc}	212.5^{b}	270.4^{bc}	282.5^{b}	304.8^{abc}	310.6^{bc}	0.190^{b}
HY1	41.89^{b}	210.6^{b}	277.5^{ab}	290.6^{a}	315.1^{a}	327.7^{a}	0.186^{bc}
HY2	37.18^{c}	203.2^{cd}	259.8^{d}	271.1^{d}	298.3^{bc}	305.2^{bc}	0.171^{d}
R	43.94^{b}	208.1^{bc}	263.5^{cd}	273.3^{cd}	293.5^{c}	302.8^{bc}	0.177^{cd}
BR	26.93^{d}	236.0^{a}	283.7^{a}	291.0^{a}	308.7^{ab}	313.6^{b}	0.224^{a}
SE[z]	1.324	2.49	3.10	2.71	4.22	3.95	0.0042

^{abcde}Means in the same column with different superscripts differ ($P<0.05$).

[x]Estimated factor to convert g of starch to ml of CO_2.

[y]Estimated first order rate constant for starch digestion.

[z]Standard error based on three observations per mean for IVDMD and four observations per mean for GP.

CHAPTER VII

THE EFFECT OF PURE YELLOW AND HETERO-YELLOW ENDOSPERM SORGHUM GRAIN HYBRIDS ON SITE AND EXTENT OF DIGESTION[1,2]

M.N. Streeter, D.G. Wagner, C.A. Hibberd and F.N. Owens

ABSTRACT

To compare the effect of two yellow (Y1 and Y2), two cream (C1 and C2) and two hetero-yellow (HY1 and HY2) sorghum grain hybrids on site and extent of digestion, sorghum grain was dry rolled and fed in an 81% grain diet to Angus-Hereford steers (342 kg) equipped with ruminal, duodenal and ileal double L type intestinal cannulae. Yellow grains had a homozygous yellow endosperm and a yellow seed coat, cream and hetero-yellow grains had a heterozygous yellow endosperm, with a white and red seed coat, respectively. Diets were fed at 1.85% of body weight (DM basis) in a 6x6 Latin square. Total tract OM digestibility (%) was greater ($P<.10$) for HY2 (71.4) and C2 (69.8) than for C1 (64.9), Y2 (62.8) and HY1 (62.6), but was not different ($P>.10$) from Y1 (67.9%). Total tract starch digestibility was correlated ($r=.80$; $P<.001$) to OM digestibility. Total tract non-ammonia nitrogen (NAN) digestibility (%) was greater ($P<.05$) for HY2 (67.8) and C2 (67.0) than

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[1]Journal Article No. of the Agric. Exp. Sta., Oklahoma State University, Stillwater.

[2]The assistance of Dr. Dave Buchanan with statistical analysis is greatly appreciated.

for C1 (62.0), Y2 (59.8) and HY1 (55.6), but was not different (P>.10) from Y1 (64.8). Ruminal starch digestion was negatively correlated (r=-.46; P<.08) to feed N flow to the duodenum. When ruminal starch digestion was expressed as a percent of total digestion, Y2 (95.3) was greater (P<.10) than Y1 (83.6), C2 (81.2) and C1 (79.0), but was not different from HY2 (90.7) or HY1 (90.5). Greater (P<.10) escape of feed N from ruminal degradation (%) was noted for HY1 (68.3) and Y2 (59.6) than for C2 (50.1) and HY2 (46.2), with C1 (58.0) and Y1 (57.9) not different from C2 or Y2. Pre-cecal starch digestibility averaged 76.2% and was more strongly correlated to ruminal starch digestibility (r=.69; P<.01) than to starch digestion in the small intestine (r=.41; P=.12). Microbial N flow to the duodenum was strongly correlated (r=.88; P<.01), while feed N flow to the duodenum was weakly correlated (r=.17; P=.52) to fractional NAN digestibility in the small intestine. Hybrids differed in site and extent of NAN digestion but, no clear advantage was observed for homozygous versus heterozygous yellow endosperm. .

(Key Words: Yellow Endosperm, Sorghum Grain, Starch, Protein, Digestion, Beef Steers.)

Introduction

Sorghum grain is a common cereal grain in feedlot diets. However, sorghum grain generally has a lower feeding value than corn (NRC, 1984) and is more variable in quality than corn, partially because of environmental influences (Wall and Ross, 1970) but also potentially due to varietal (Miller et al., 1962) and hybrid differences (Norris and Rooney, 1970). Variation noted in cattle performance associated with

different sorghum grain hybrids or varieties (McCollough et al., 1972; Maxson et al., 1973; Goldy et al., 1987) may partially be due to differences in digestibility (McCollough and Brent, 1972).

Differences in site and extent of digestion have been noted with pureline sorghum grain varieties (Streeter et al., 1989b); therefore, one might expect differences among various hybrids (Norris and Rooney 1970). Endosperm characteristics and ruminal and intestinal digestion may differ among sorghum grain hybrids altering efficiency of energy and nitrogen utilization (Black, 1971). The extent to which homozygous and heterozygous yellow endosperm sorghum grain hybrids may differ in site and extent of digestion is unclear. The objective of this study was to quantify the differences which may exist between sorghum grain hybrids with homozygous and heterozygous yellow endosperm in chemical composition, extent of starch digestion in the rumen and in the small and large intestines and extent of grain protein escape to the small intestine in beef cattle.

Materials and Methods

Six genetically unique hybrid sorghum grains representing two yellow (Y1 and Y2; Paymaster 1096 Y and Dekalb 41Y), two cream (C1 and C2; PAG 575 and Funks G-550) and two hetero-yellow (HY1 and HY2; PAG 5572 and Funks G-522DR)[3] sorghum grain hybrids were grown under dryland conditions during the summer of 1986 in southeast Kansas. Hybrids within common endosperm type and seed coat color were of different genetic background. Rainfall totaled 38 cm and was evenly distributed

[3]Sorghum grain seed donated by Cargil, Funk's and Dekalb is greatly appreciated.

throughout the growing season. Yellow hybrids had a homozygous yellow endosperm with a yellow seed coat. Cream hybrids had a heterozygous yellow endosperm with a white seed coat. Hetero-yellow types had a heterozygous yellow endosperm with a red seed coat (Table 13).

Laboratory Trial

Grain and diet samples were ground through a 1-mm screen prior to chemical analysis and through a .4-mm screen prior to starch analysis. Dry matter, CP, OM (AOAC, 1975) and starch as alpha-linked glucose (MacRae and Armstrong, 1968, modified by the use of a glucose determination kit[4]) content were determined. Grains were additionally analyzed for pepsin[5] insoluble nitrogen (PIN; Goering and Van Soest, 1970) and sodium chloride soluble nitrogen (NaCl-N; Waldo and Goering, 1979). Berry size of sorghum grain hybrids was measured by weighing 100 randomly selected pre-dried berries. The volume of individual sorghum berries was determined by measuring the volume of toluene displaced by 100 pre-dried berries. Density was calculated by dividing the mass of 100 berries by the volume displaced. The geometric mean diameter of dry rolled grain particles was determined by the procedure of Ensor et al. (1970). Relative distribution of particles among sieves and geometric mean particle size were used as an indirect measure of hardness or corneousness of sorghum grain (Pomeranz, 1986).

Steer Trial

[4]Glucose oxidase; Sigma Chemical Co., St. Louis, Mo., USA.
[5]Sigma Chemical Co., St. Louis, Mo., USA.; EC 2.4.23.1

Six Angus-Hereford steers (352 kg ± 8.6) were surgically fitted, while under local anesthesia, with permanent ruminal and double L type duodenal (4 cm distal to the pylorus) and ileal (20 cm cranial to the ileo-cecal junction) cannulae (Streeter et al., 1989d). Steers were fed diets (Table 14) at 1.85% (DM basis) of individual body weight in a 6x6 Latin square. Feed intake was lower than usually noted in a feedlot or production situation (ad libitum), but consistently higher intakes are difficult or impossible to maintain when steers are individually penned and fed under these experimental conditions. Diets were formulated to meet NRC (1984) requirements for CP, Ca and P for medium-framed steer calves gaining .7 kg/d. Urea was used as the sole source of supplemental N, and cottonseed hulls (containing approximately 4.3% total dietary N) were used as the roughage source so that feed N reaching the duodenum would be primarily of grain origin (approximately 97.7%). Molasses was included at 3% of diet DM (containing approximately 2.2% of total dietary N) to control dust. Chromic oxide (.20% of diet DM) was used as an indigestible marker.

Experimental periods lasted 10 d, with d 1 through 7 for diet adaptation and 8 through 10 for feed, digesta and fecal sampling. Steers were fed equal portions four times daily. Steers were pulse dosed with 1 g of ytterbium (Yb) in the form of Yb-labeled grain (Teeter et al., 1984) and 1 g of cobalt (Co) in the form of Co·EDTA (Uden et al., 1980) on d 8 at 0800 h. Digesta samples were collected at 1200, 1800 and 2400 h on d 8, 0600, 1500 and 2100 h on d 9 and 0300 and 0900 h on d 10. This schedule allowed samples to be collected every 3 h in a 24-h period. Digesta (250 ml duodenal and 250 ml ileal fluid at each time) and fecal grab samples, after pH determination,

were composited across time and d within steer for each period and stored at 2° C until the end of each period. Additionally, 150 ml of duodenal fluid was obtained at each time, immediately dried at 55° C for 48 h in a forced air oven and ground through a 1-mm screen prior to Yb and Co analysis. Ruminal fluid for ammonia (NH_3-N) determination was collected at 1500 and 2100 h on d 9 and 0300 and 0900 h on d 10. Ruminal fluid samples were strained through four layers of cheesecloth and acidified (5 ml of 20% H_2SO_4 per 100 ml of fluid) immediately following determination of pH. Aliquots of ruminal, duodenal and ileal fluids and feces were obtained and stored at -20° C at the end of each period.

Ruminal fluid used to estimate microbial N, purine N, and OM was strained through four layers of cheesecloth into collection flasks surrounded by ice for each steer on d 10 of periods 2, 3, 4, and 6 at 1400 h. Equal volumes of ruminal fluid from each steer were composited within period (Streeter et al., 1989f). Bacteria were isolated from composite ruminal fluid samples 1 d after collection by differential centrifugation (Weakley, 1983), frozen (-20° C), lyophilized and ground with a mortar and pestle prior to analysis.

Feed, digesta and fecal samples were lyophilized prior to grinding through a 1-mm screen before chemical analysis. Feed, duodenal, ileal and fecal samples were analyzed for chromic oxide (Fenton and Fenton, 1979) in addition to all components used in the laboratory trial, except PIN and NaCl-N. Duodenal and bacterial samples also were analyzed for purine N (RNA basis; Zinn and Owens, 1986). Ruminal NH_3-N was determined by the procedure of Brodrick and Kang (1980). Digesta and fecal NH_3-N was determined as described by Streeter et al. (1989c).

Partial digestion coefficients and amounts of different components presented to and disappearing from segments of the digestive tract were calculated from chromic oxide concentrations and intakes. Chyme flows were calculated as chromic oxide intake (g/d) multiplied by the fractional chromic oxide concentration. Microbial N reaching the duodenum was calculated as duodenal purine N divided by the mean ratio ($12.54 \pm .395$) of microbial purine N (RNA basis) to total N for the trial. Feed N (plus endogenous N) reaching the duodenum was calculated as duodenal N minus NH_3-N and microbial N. Organic matter reaching the duodenum was corrected for microbial OM based on means determined for microbial ash (18.2%) and CP (29.6%). True ruminal OM disappearance was used to calculate the efficiency of microbial protein synthesis (g microbial N/kg OM truly fermented in the rumen). Particulate passage rate (%/h) and ruminal liquid dilution rate (%/h) were estimated by the slope of the regression of the natural logarithm of Yb and Co concentrations, respectively, against time. Samples determined to be on the up-slope of Yb and Co concentration curves were not included in the regression.

Statistical Analysis

The data from the laboratory trial were described by the following model: $Y_{ijk} = \mu + D_i + G_j + E_{ijk}$, where Y_{ijk} is the observed value of interest, D is the duplicate sample and G is the grain. The components μ, D_i and G_j were treated as fixed effects of all records of duplicate i and grain j. Random errors, E_{ijk}, were specific to each observation. The data from the animal trial were described by the followed model: $Y_{ijkl} = \mu + S_i + P_j + H_k + E_{ijkl}$, where Y_{ijkl} is the observed value of

interest, S is steer, P is period and H is the sorghum grain hybrid. The components μ, S_i, P_j and H_k were treated as fixed effects of all records of steer i, period j and hybrid k. Random errors, E_{ijkl}, were specific to each observation. Differences between least squares means were detected by protected LSD (Steel and Torrie, 1980).

Results and Discussion

Laboratory Trial

Sorghum grain hybrids were not different (P>.10) in CP content (Table 15). Starch content was greater (P<.10) for Y1 (79.9%) and C1 (78.4) than for HY2 (76.8), Y2 (76.1) and HY1 (74.4), with C1 (78.4) and C2 (77.4) being intermediate (P>.10). NaCl-N content tended to be greater for Y1 (26.7% of N) and lower for HY1 (19.6) than other hybrids. Complete mixed feeds containing grains Y1, Y2, C1, C2 and HY1 had greater (P<.05) starch than HY2. Diets were formulated to be equal in CP; hence, no differences were expected.

Physical characteristics of the grains (Table 15) varied considerably. Hybrids C2 (2.61 g/100 berries) and HY1 (2.53) had greater (P<.05) berry size and C1 (1.98) had smaller berry size than did other sorghum hybrids. Berry volume (μl) was greater (P<.05) for HY1 (20.5) and C2 (20.0) than for HY2 (17.5), Y2 (16.5) and C1 (15.5), with Y1 (18.0) not different (P>.05) from C2, HY2 or Y2. Because berry size reflected berry volume (r=.72; P<.10), no differences in berry density were noted. Geometric mean diameter (GMD) of dry rolled grain particles was not different (P>.10) among sorghum hybrids, although HY2 (1,866 μm) tended to have a greater GMD than other hybrids. Particle size distribution differences were larger than expected based on GMD.

HY2 (44.08) had a larger proportion (P<.10) of 2,828 μm particles than other grains. Dry rolling of HY1 (30.86) and C1 (30.62) resulted in more (P<.10) 2,828 μm particles than C1 (67.35), HY1 (66.03) and HY2 (52.82), but not more than Y1 (74.20) or Y2 (73.29). All grains were greater than (P<.10) HY2. Differences in particle size distribution may reflect differences in hardness or amount of peripheral endosperm.

Smaller differences were observed in this study than that of Streeter et al. (1989c), perhaps because grains were rolled to a larger GMD reducing the potential for differences in peripheral endosperm content to be indirectly reflected in particle size distribution (Pomeranz, 1986). However, if all grains had contained equal amounts of peripheral endosperm and were of similar DM content, larger berries (C2 and HY1) should have resulted in more small particles than other hybrids. This was true for C2, but not HY1; hence one might conclude that HY1 contained more peripheral endosperm than C2 or contained more moisture at the time grains were dry rolled. The amount of peripheral endosperm is dependent upon total N content, continuity of matrix protein (Rooney and Pflugfelder, 1986) and hybrid (Hoseney et al., 1974). Additionally, hybrids with the same endosperm and seed coat color may differ in the amount of peripheral endosperm due to different amounts in the parental varieties (Norris and Rooney, 1970). Because peripheral endosperm cells are resistant to both enzymatic and physical degradation (Rooney and Pflugfelder, 1986), one would expect sorghum types with more peripheral cells to result in larger particle size. Larger particles may reduce digestion of starch (Kim and Owens, 1985) and perhaps N due to less surface area for microbial and enzymatic attach. Larger particles, resulting from greater peripheral endosperm

content, also may reduce ruminal starch and protein degradation due to greater density (Hoseney et al., 1974), which may decrease retention time within the rumen compared to smaller, less dense particles (Faichney, 1986). Additionally, proteins in the peripheral endosperm may shroud starch granules (Seckinger and Wolf, 1973; Harbers and Davis, 1974, Hoseney et al., 1974) limiting microbial and enzymatic starch digestion.

Steer Trial

Differences in fecal output tended to reflect total tract OM digestibility (Table 16). Total tract OM digestibility (%) was greater ($P<.10$) for HY2 (71.4) and C2 (69.8) than for C1 (64.8), Y2 (62.8) and HY1 (62.6), with Y1 (67.9) not different ($P>.10$) from C2, HY2 or C1. Total tract starch digestibility was correlated ($r=.80$; $P<.001$) to total tract OM digestibility; however, differences in starch digestibility among sorghum hybrids were not noted ($P>.10$). Hibberd et al. (1985) and Streeter et al. (1989b) reported no differences in total tract starch digestibility among three sorghum grain hybrids and four pureline sorghum varieties, respectively. Streeter et al. (1989c) noted no difference in total tract starch digestibility of four diverse sorghum hybrids. However, McCollough and Brent (1972) reported differences in total tract NFE digestibility among eight sorghum hybrids. Rooney and Pflugfelder (1986) suggested sorghum grain with a yellow endosperm is of higher "feeding value" than sorghum with a non-yellow endosperm. Streeter et al. (1989e) noted in vitro enzymatic starch availability tended to rank hybrids in a similar order to our estimates of total tract starch digestibility.

Total tract starch digestibility was positively correlated to ruminal starch digestibility (r=.76; P<.001), while being weakly correlated to starch digestibility in the small intestine (r=.10; P<.71) and large intestine (r=-.03; P<.91). This suggests that increased total tract starch digestion is obtained most readily by increasing ruminal starch digestion even though improved energetic efficiency may be obtained from digestion of starch in the small intestine (Black, 1971).

Total tract non-NH_3 N (NAN) digestibility (%) was greater (P<.05) for HY2 (58.2) and C2 (58.1) than for C1 (53.5), Y2 (51.8) and HY1 (48.2), but not different (P>.10) from Y1 (56.2). Y1 was greater (P<.05) than Y2 and HY1, but not different (P>.10) from C1. Differences in total tract NAN digestibility may be responsible for differences in total tract OM digestibility. McCollough and Brent (1972) noted only slight variation in N digestibility among diverse sorghum hybrids when bird resistant types were ignored. Streeter et al. (1989b) reported large differences in total tract NAN digestibility of four divergent sorghum grain varieties; however, differences were due to bird resistance, not endosperm characteristics. In another study (Streeter et al., 1989c) no differences in total tract NAN digestibility were noted among four divergent sorghum grain hybrids and corn.

Ruminal Digestion. Chyme flow (liters/d) was greater (P<.10) for Y2 (64.7) and HY1 (63.8) than for Y1 (55.7), C2 (55.3) and HY2 (51.6), with C1 (58.6) not different from Y2, HY1, Y1 or C2 (Table 17). Elevated duodenal chyme flow has been reported for sorghum grains high in condensed tannin (Hibberd et al., 1985; Streeter et al., 1989b) or

when sorghum was high moisture processed and blended with corn (Streeter et al., 1989f). Reasons for increased chyme flow noted among non-bird resistant sorghum hybrids with yellow endosperm are unclear. Differences in particulate passage rate (%/h) and ruminal liquid dilution rate (%/h) were not observed (P>.10). Particulate passage rate was not correlated (r=.08; P>.10) to duodenal chyme flow, while liquid dilution rate tended to be negatively correlated (r=-.40; P<.14) to chyme flow.

Ruminal pH was not different (P>.10) due to sorghum grain hybrid, averaging 6.04. Additionally, ruminal NH_3-N levels were not altered (P>.10) by hybrid, averaging 4.39 mg/dl. Satter and Slyter (1974) reported a minimum NH_3-N level of 5 mg/dl for maximal microbial N production with forage-based diets. Weakley (1983) suggested higher values may be needed to obtain maximum ruminal OM digestion. Much lower ruminal NH_3-N concentrations (1 to 3 mg/dl) are commonly noted with feedlot type diets. Lower ruminal NH_3-N levels may result from rapid utilization of NH_3-N due to readily available energy from starch. Additionally, low ruminal NH_3-N concentrations may not be representative of NH_3-N levels surrounding bacteria attached to feed particles (Czerkawski, 1986).

Starch flowing to the duodenum (r=.91; P<.01) and ruminal starch digestibility (r=.91, P<.01) were highly correlated to flow and digestion of true OM; therefore, OM will not be discussed. Differences in starch flow to the duodenum and ruminal starch digestibility were small (P>.10). Starch digestibility (%) tended to be greater for HY2 (76.4) and lower for C1 (64.9) than for other sorghum hybrids. Somewhat lower (353.6 g/d) starch intake for HY2 may have resulted in

the higher starch digestibility. Low ruminal NH_3-N levels may have limited ruminal starch digestibility (Weakley, 1983); however, ruminal NH_3-N was not correlated to ruminal starch digestion (r=-.08; P=.77). Previous reports have suggested significant differences, although small, in ruminal starch digestibility among several pureline sorghum varieties (Streeter et al., 1989b) and several hybrids (Hibberd et al., 1985; Streeter et al., 1989c). However, Waldo (1973) suggested large variation in ruminal starch digestibility of sorghum grain among literature reports. Perhaps the similarity of grain endosperm (color) in our study may explain the lack of large differences noted in ruminal starch digestibility among the grains tested.

When ruminal starch digestion was expressed as a percent of total starch digestion, Y2 (95.3%) was greater (P<.10) than Y1 (83.6), C2 (81.2) and C1 (79.0), with HY1 (90.5) and HY2 (90.7) not different (P>.10) from Y2 or Y1. The importance of the rumen as a site of sorghum grain starch digestion is further emphasized by the strong correlation between ruminal starch digestibility and total tract starch digestibility (r=.76; P<.001). This relationship may be of greater importance for sorghum grain than other cereal grains, because sorghum starch escaping ruminal digestion may be heavily encapsulated in a protein matrix that may limit intestinal starch digestion (Harbers and Davis, 1971; Sullins and Rooney, 1974).

Non-NH_3 N flowing to the duodenum (g/d) was greater (P<.10) for HY1 (132.3) than for C2 (116.2), with Y1 (120.0), Y2 (124.8) and C1 (125.4) not different (P>.10) from HY1 or C1. All sorghum grain hybrids had greater (P<.10) NAN flow to the small intestine than HY2 (100.4). Although differences in feed N flowing to the small intestine

tended to reflect NAN flow, NAN flow was correlated more strongly (r=.79; P<.001) to microbial N flow than to feed N flow (r=.45; P<.10) to the duodenum. Microbial N flowing to the duodenum was not different (P>.10) due to hybrid and averaged 73.1 g/d. However, HY1 (77.3) tended to be greater and HY2 (68.3) tended to be less than other hybrids. More (P<.10) HY1 (58.3 g/d) feed N reached the duodenum than Y1 (48.7), C2 (43.3 or HY2 (39.0) feed N, with Y2 (51.8) and C1 (49.6) not different from HY1, Y1 or C2. Feed N digestibility within the rumen and escape of N from ruminal degradation reflected differences in feed N flow to the duodenum. HY2 (65.3) had greater (P<.10) feed N digestibility (%) than Y1 (56.8), C1 (56.5), Y2 (55.2) and HY1 (48.8), with C2 (62.6) not different (P>.10) from HY2, Y1 or C1. Conversely, feed N escape of ruminal degradation (%) was greater (P<.10) for HY1 (68.3) than for C1 (58.0), Y1 (57.9), C2 (50.1) and HY2 (46.2), with Y2 (59.6) not different (P>.10) from C1 and Y1. C1 and Y1 were greater (P<.10) than HY2, but not different (P>.10) from C2. Hibberd et al. (1985) reported 69% of dry rolled sorghum grain N escaped ruminal degradation, while Theurer (1979) noted 58% of dry rolled sorghum grain N escaped ruminal degradation.

The protein and starch fractions in sorghum grain adhere more tightly than in corn (Rooney and Pflugfelder), particularly in the peripheral endosperm. Therefore, Rooney and Riggs (1971) and Wagner (1984) have postulated a relationship between the peripheral endosperm content of sorghum grains and ruminal starch digestibility. Additionally, scanning electron microscopy observations by several workers (Seckinger and Wolf, 1973; Harbers and Davis, 1974; Hoseney et al., 1974; Sullins and Rooney 1974) indicate that protein barriers may

limit both microbial and enzymatic starch degradation. In our study daily feed N flow (g/d) to the duodenum was positively correlated to starch flow to the duodenum (r=.48; P<.06) and negatively correlated to ruminal starch digestibility (r=-.46; P<.08). Correlations supporting the hypothesis that protein encapsulation of starch granules limits starch digestibility have not been noted previously. Perhaps relationships in other reports involving specific hybrids or varieties of sorghum grain have not been observed because of bird resistant types, processing methods or corn included as dietary treatments.

Efficiency of microbial protein production (g of microbial N/kg OM truly fermented) ranged from 18.8 (C1) to 15.6 (HY2); however, differences in the efficiency of microbial protein production (MOEFF) were not noted (P>.10). Duodenal chyme flow was highly correlated (r=.76; P<.001) to MOEFF. Owens and Issacson (1977) noted that MOEFF can be enhanced by increasing liquid dilution rate in vitro. Recently, Froetschel et al. (1989) utilized slaframine to stimulate salivary flow and liquid dilution rate, noting a linear increase in MOEFF with increasing liquid dilution rate. In our study, MOEFF was only weakly correlated to liquid dilution rate (r=.34; P=.22) and particulate passage rate (r=-.12; P=.64).

Pre-Cecal Digestion. Chyme flow past the ileum (Table 18) ranged from 16.1 (Y1) to 12.3 (C2) and averaged 14.3 liters/d. Chyme flow was negatively correlated to ruminal (r=-.63; P<.05), pre-cecal (r=-.57; P<.05) and total tract (r=-.54; P<.05) starch digestibility. Correlations may result from low pre-cecal starch and OM digestibility, with chyme being comprised of total liquid and solid matter, but also

may indicate that the rate of chyme flow limits the extent of starch digestion.

Starch flowing to the cecum (r=.96; P<.001) and pre-cecal starch digestibility (r=.94; P<.001) were highly correlated to OM; hence, only starch will be discussed. C1 (1165.2) tended (P>.10) to have greater starch flow to the cecum (g/d) than other sorghum hybrids. Pre-cecal starch digestibility was not different (P>.10) among sorghum hybrids, averaging 76.2%, but HY1 (79.6) tended (P>.10) to have greater pre-cecal starch digestibility (%) than C1 (69.5), with other grains being intermediate. Streeter et al. (1989b) noted greater pre-cecal starch digestibility for sorghum grain varieties with a waxy compared to a normal endosperm; however, Hibberd et al. (1985) and Streeter et al. (1989c) noted no difference in pre-cecal starch digestibility among non-bird resistant sorghum hybrids with a normal endosperm. Pre-cecal starch digestibility (% of intake) was strongly correlated to (r=.69; P<.01) ruminal starch digestibility, while being less strongly correlated (r=.41; P=.12) to starch digestion within the small intestine. This indicates that the rumen accounts for the majority of pre-cecal starch digestion, yet grains tended to be ranked in the same order both in the rumen and in the small intestine. Pre-cecal starch digestibility may have been limited by protein encapsulation of starch granules (Rooney and Pflugfelder, 1986). Non-NH_3 N (r=-.55; P<.05) and feed N flow (r=-.39; P=.14) to the duodenum tended to be negatively correlated to pre-cecal starch digestibility, while starch flow to the cecum tended to be positively correlated with NAN flow (r=.54; P<.05) and feed N flow (r=.39; P=.13) to the small intestine. The combination of NAN and feed N correlations with pre-cecal starch digestibility

suggests that protein encapsulation of starch granules reduced pre-cecal starch digestion in our study. Protein encapsulation of starch granules may inhibit the rate at which amylase contacts starch granules. When expressed as a percent of total starch digestion, pre-cecal starch digestibility was greater ($P<.10$) for Y2 (101.4), Y1 (95.3) and HY1 (85.0) than for C1 (84.4), with C2 (91.4) and HY2 (91.2) not different ($P>.10$) from Y1, HY1 or C1. Pre-cecal digestion of starch may be more efficient than fermentation in the large intestine.

Flow of NAN to the cecum ranged from 48.8 (C2) to 58.2 (C1), averaging 54.0 g/d. Pre-cecal NAN digestibility (%) was greater ($P<.10$) for C2 (57.8) than for HY1 (50.2) and C1 (49.8), with Y1 (54.2) and Y2 (53.0) not different ($P>.10$) from C2, HY1 or HY2 (55.2). Greater ($P<.10$) pre-cecal NAN digestibility was noted for HY2 than for C1. Hibberd et al. (1985) noted no difference in pre-cecal NAN digestibility among a hetero-yellow, a red and a bird resistant sorghum hybrid. Streeter et al. (1989b), however, noted greater pre-cecal NAN digestibility for two non-bird resistant sorghum grain varieties compared with two bird resistant types.

Feed N flow to the duodenum was positively correlated to NAN flow to the cecum ($r=.72$: $P<.01$) and negatively correlated to pre-cecal NAN digestibility ($r=-.66$; $P<.01$). This may indicate that feed N, primarily of sorghum origin, is less digestible in the small intestine than microbial N. Neudoerffer et al. (1971) concluded that microbial protein was more digestible than protein in cereal grains. Extensive escape of poor quality feed N from ruminal digestion may reduce starch digestion in the small intestine, not only through protein shrouding of starch granules, but also by limiting the supply of essential amino

acids available for absorption and amylase synthesis. Johnson et al. (1977) suggested that pancreatic amylase concentrations can be enhanced in response to high starch diets only when an adequate supply of essential amino acids are fed to non-ruminants. Streeter et al. (1989c) hypothesized that protein quality could limit enzymatic starch digestion of sorghum grain.

Digestion in the Intestine. Differences in the small intestine were small, but tended to reflect ruminal observations (Table 19). Starch disappearance from the small intestine ranged from 357.0 (Y1) to 131.6 (HY2) and averaged 263.1 g/d. Starch digestibility in the small intestine (% of entry) was very low and not different (P>.10) among sorghum hybrids. However, Y1 (25.4%) and C2 (25.2%) tended to have greater starch digestibility within the small intestine than C1 (5.6) and HY2 (4.6), with Y2 (16.9) and HY1 (16.8) intermediate. When expressed as a percent of dietary starch intake, starch digestibility in the small intestine was extremely low for all sorghum hybrids, ranging from 3.1 to 9.9%. Owens et al. (1986) developed a regression equation allowing the estimation of gain to feed ratio (G:F) from starch digestibility in the rumen and small intestine (G:F=.159 x ruminal digestibility + .227 x small intestinal starch digestibility; r^2=.60; $SE_{y.x}$=.006). Estimated G:F for HY1 (.133) and Y2 (.132) tended to be greater than for C1 (.114), with other grains closer to HY1 and Y2 than C1 (Figure 5).

Starch flow (g/d) to the duodenum was weakly correlated (r=.33; P=.18) to starch disappearance from the small intestine. Owens et al. (1986) noted a correlation of .77 across several trials involving processed and dry rolled corn and sorghum grains. Owens et al. (1986)

suggested that the strong correlation between starch flow to the small intestine and disappearance of starch from the small intestine indicated that physiological factors probably did not limit the extent of starch digestion. A much weaker correlation was noted in our study. This may have resulted from protein shrouding of starch granules as previously stated, or increased chyme flow. In our study, starch disappearance ($r=.53$; $P<.05$) and starch digestibility as a percent of starch entry ($r=.45$; $P<.07$) or as a percent of starch intake ($r=.56$; $P<.05$) were positively correlated to duodenal chyme pH. A chyme pH below that optimal for amylase activity has been investigated as a factor reducing pancreatic amylase activity (Armstrong and Beaver, 1969; Orskov et al., 1970) and starch digestion in the small intestine. However, Remillard and Johnson (1984) infused amylase into the jejunum with and without additional buffer, but failed to enhance starch digestion in the small intestine. Therefore, it is unclear if our correlation between duodenal chyme pH and digestion of starch in the small intestine is real or an artifact.

Starch digestion in the small intestine (% of intake) tended to be negatively correlated ($r=-.42$; $P<.10$) to ruminal starch digestibility. Owens et al. (1986) noted a stronger negative correlation ($r=-.75$) between ruminal starch digestibility and starch digestion in the small intestine. A negative correlation may indicate that easily accessible starch is extensively degraded in the rumen; hence, starch flowing to the small intestine contains more limit dextrins or core starch than native grain starch presented to the rumen. Support for this hypothesis has been noted by Froetschel et al. (1989), where a linear decrease in ruminal starch digestion, resulting from increased liquid

dilution rate, linearly increased post-ruminal starch digestion. However, the large intestine could have accounted for compensatory post-ruminal starch digestion (Hibberd et al., 1985; Streeter et al., 1989b) noted by Froetschel et al. (1989).

Difference in NAN disappearance (g/d), partial digestibility (% of entry) and digestibility (% of intake) in the small intestine were small (P>.10). When partial NAN digestibility was expressed as a percent of total NAN digestion, HY1 (138.9) was greater (P<.10) than C1 (109.5), Y1 (107.4), C2 (102.8) and HY2 (79.6), with HY2 less (P<.10) than all hybrids except C2. Y2 (119.4) was not different ((P>.10) for HY1, C1, Y1 or C2. Values are greater than 100% because NAN flow to the duodenum exceeded N intake, indicating extensive N recycling to the rumen (Kennedy and Milligan, 1980). Values greater than 100% could also result from urea-N recycling to the large intestine. A strong positive correlation (r=.69; P<.01) was detected between microbial N flow to the duodenum and partial NAN digestibility in the small intestine, while a weak negative correlation (r=-.33; P=.21) was noted between feed N flow to the duodenum and partial NAN digestibility in the small intestine. Additionally, microbial N flow to the duodenum was more strongly correlated (r=.88; P<.001) and feed N flow to the duodenum much less strongly correlated (r=.17;P=.52) to NAN disappearance from the small intestine than observed for partial NAN digestibility. These correlations further support the concept that microbial N is more digestible in the small intestine than feed N. Perhaps a larger portion of NAN disappearing from the small intestine is of microbial origin than feed origin.

Differences in starch and NAN digestion in the large intestine were small (Table 20). The combination of starch, OM and NAN disappearance and partial digestibilities tended to be indicative of starch fermentation; however differences were less consistent than those observed by Hibberd et al. (1985) and Streeter et al. (1989b). Starch disappearance from the large intestine averaged 200 g/d, only slightly less than observed within the small intestine (263 g/d).

In summary, sorghum grain hybrids differed in site and extent of starch and N digestion, with differences in N larger than for starch. Nitrogen digestion may have varied among sorghum hybrids because of different parental varieties. Because starch digestibility was generally positively correlated to N digestibility and starch granules may have been embedded in poorly digestible protein, larger differences in starch digestibility may be observed with greater DMI or increased particulate passage rate.

TABLE 13

DESCRIPTIVE CHARACTERISTICS OF
SORGHUM GRAIN HYBRIDS

Sorghum hybrid	Seed Coat color	Endosperm color	Endosperm cross
Y1 and Y2	yellow	homozygous yellow	yellow x yellow
C1 and C2	white	heterozygous yellow	white x yellow
HY1 and HY2	red	heterozygous yellow	white x yellow

TABLE 14

INGREDIENT COMPOSITION OF EXPERIMENTAL DIETS

Ingredient	% of DM
Grain	81.2
Cottonseed hulls	12.0
Molasses	3.0
Supplement	
Urea	1.0
Calcium carbonate	.93
Dicalcium phosphate	.44
Potassium chloride	.57
Sodium sulfate	.36
Trace mineralized salt	.25
Chromic oxide	.20
Vitamin A premix[a]	.05

[a]2200 IU/kg DM.

TABLE 15

CHEMICAL AND PHYSICAL CHARACTERISTICS OF SORGHUM GRAIN HYBRIDS AND COMPLETE MIXED FEEDS (DM BASIS)

Item	Y1	Y2	C1	C2	HY1	HY2	SE
Grain							
CP	9.5	10.5	9.7	9.7	9.6	10.3	.15
Starch	79.9^{w}	76.1^{yz}	78.4^{wx}	77.4^{xy}	74.4^{z}	76.8^{xy}	.69
ADF	7.3	6.9	9.6	6.1	9.0	11.2	1.91
NaCl soluble nitrogen, % of total N	26.7	23.2	23.6	22.0	19.6	22.3	1.57
Pepsin insoluble nitrogen, % of total N	11.1	12.5	12.5	10.8	12.2	11.5	.57
Berry size, g/100 berries	2.22^{b}	2.13^{b}	1.98^{c}	2.61^{a}	2.52^{a}	2.18^{b}	.030
Berry volume, μl/berry	18.0^{bc}	16.5^{cd}	15.5^{d}	20.0^{ab}	20.5^{a}	17.5^{cd}	.58
Density, g/ml	1.24	1.29	1.28	1.32	1.24	1.25	.032
Feed							
CP	11.3	11.5	11.5	11.4	11.4	11.6	.15
Starch	59.5^{a}	59.8^{a}	60.2^{a}	59.4^{a}	59.8^{a}	55.2^{b}	.98
ADF	13.6	12.0	12.6	13.1	12.6	12.1	.65
Particle Size							
5,656 μm	.3	.3	.1	.1	.2	.1	.07
2,828 μm	22.9^{yz}	24.4^{yz}	30.6^{y}	16.5^{z}	30.9^{y}	44.1^{x}	4.28
1,414 μm	74.2^{xy}	73.3^{xy}	67.4^{y}	81.9^{x}	66.0^{y}	52.8^{z}	4.21
707 μm	1.0	1.5	1.3	1.4	1.8	1.9	.32
354 μm	.4	.3	.2	.1	.4	.6	.17
177 μm	.4	.2	.3	.2	.6	.5	.13
Geometric mean diameter (GMD), μm	1,670	1,654	1,712	1,566	1,702	1,866	54.1

^{abc}Means in the same row with different superscripts differ ($P<.05$).

^{wxyz}Means in the same row with different superscripts differ ($P<.10$).

TABLE 16

EFFECT OF SORGHUM GRAIN HYBRID
ON TOTAL TRACT DIGESTION

Item	Y1	Y2	C1	C2	HY1	HY2	SE
Fecal output,							
kg/d	6.9^{y}	7.7^{xy}	7.4^{xy}	6.8^{y}	8.0^{x}	5.6^{z}	.40
Fecal pH	5.74^{yz}	6.02^{x}	5.78^{xyz}	5.66^{z}	5.92^{xy}	6.02^{x}	.104
Feces, g/d							
OM	$1,966^{xyz}$	$2,241^{wx}$	$2,102^{wxy}$	$1,841^{yz}$	$2,266^{w}$	$1,697^{z}$	119.6
Starch	740.8	857.5	709.7	622.1	772.0	537.9	99.65
Total N	50.9^{cd}	56.7^{ab}	54.6^{bc}	49.0^{d}	61.1^{a}	48.9^{d}	1.98
Non-NH_3 N	50.3^{cd}	55.9^{ab}	53.8^{bc}	48.5^{cd}	60.4^{a}	48.2^{d}	1.98
Total tract digestibility, %							
OM	67.9^{xy}	62.8^{z}	64.9^{yz}	69.8^{x}	62.6^{z}	71.4^{x}	1.88
Starch	80.8	77.0	81.4	83.4	80.1	84.2	2.45
Total N	55.6^{ab}	51.1^{cd}	52.8^{bc}	57.7^{a}	47.5^{d}	57.6^{a}	1.53
Non-NH_3 N	56.2^{ab}	51.8^{cd}	53.5^{bc}	58.1^{a}	48.2^{d}	58.2^{a}	1.54
Total tract disappearance, g/d							
OM	4092^{xy}	3763^{z}	3887^{yz}	4263^{x}	3762^{z}	4254^{x}	121.3
Starch	3049	2894	3076	3166	3068	2891	116.5
N	64.1^{xy}	59.0^{y}	61.2^{y}	67.0^{x}	54.9^{z}	67.1^{x}	2.23
Non-NH_3 N	64.8^{xy}	59.8^{yz}	62.0^{y}	67.5^{x}	55.6^{z}	67.8^{x}	2.26

^{abc}Means in the same row with different superscripts differ ($P<.05$).

^{xyz}Means in the same row with different superscripts differ ($P<.10$).

TABLE 17

EFFECT OF SORGHUM GRAIN HYBRID
ON RUMINAL DIGESTION

Item	Y1	Y2	C1	C2	HY1	HY2	SE
Intake, g/d							
OM	6,059	6,004	5,989	6,104	6,027	5,951	10.7
Starch	3,790	3,752	3,786	3,789	3,794	3,428	64.2
Total N	115.0	115.6	115.6	115.9	115.7	115.7	.21
Non-urea N	85.8	86.8	86.8	86.7	86.6	87.2	.16
Ruminal pH	6.06	6.00	5.98	6.00	6.07	6.13	.046
Ruminal NH_3 N, mg/dl	4.89	6.02	4.31	3.86	3.82	3.45	.876
Particulate rate of passage, %/h	4.51	4.02	5.12	3.56	4.19	4.71	.730
Liquid dilution rate, %/h	3.94	3.85	4.62	4.36	4.60	4.21	.330
Duodenal chyme pH	2.51	2.55	2.59	2.55	2.46	2.46	.054
Entering the duodenum, g/d							
Chyme, liters	55.7^{yz}	64.7^{x}	58.6^{xy}	55.3^{yz}	63.8^{x}	51.6^{z}	3.60
Total OM	3,176	2,912	3,197	3,087	3,253	2,700	227.2
Microbial OM	1,231	1,262	1,309	1,260	1,336	1,181	104.6
Feed OM	1,945	1,651	1,888	1,827	1,916	1,519	198.5
Starch	1,231	991	1,329	1,215	1,113	799	155.1
Total N	124.0^{xy}	128.9^{xy}	129.5^{xy}	120.2^{y}	136.1^{x}	103.6^{z}	6.86
Non-NH_3 N	120.0^{xy}	124.8^{xy}	125.4^{xy}	116.2^{y}	132.3^{x}	100.4^{z}	6.79
Microbial N	71.2	73.0	75.8	72.9	77.3	68.3	6.05
Feed N	48.7^{y}	51.8^{xy}	49.6^{xy}	43.3^{yz}	58.3^{x}	39.0^{z}	4.14
Ruminal digestibility, %							
OM (true)	67.5	72.2	68.2	70.1	67.7	74.0	3.25
Starch	67.1	73.1	64.9	67.7	69.9	76.4	4.09
Feed N							
Total N	56.8^{xy}	55.2^{yz}	56.5^{xy}	62.6^{wx}	48.8^{z}	65.3^{w}	3.26
Non-urea N	42.1^{xy}	40.4^{yz}	42.0^{xy}	49.9^{wx}	31.7^{z}	53.7^{w}	4.32
Ruminal escape of feed N, %	57.9^{xy}	59.6^{wx}	58.0^{xy}	50.1^{yz}	68.3^{w}	46.2^{z}	4.32
True efficiency of microbial protein production, g MP/kg OM truly fermented	17.5	16.7	18.8	17.2	18.7	15.6	1.74
Ruminal digestibility, % of total digestion							
True OM	100.7^{b}	116.8^{a}	105.0^{b}	100.7^{b}	109.0^{ab}	104.0^{b}	3.80
Starch	83.6^{yz}	95.3^{x}	79.0^{z}	81.2^{z}	90.5^{xy}	90.7^{xy}	4.06

^{abc}Means in the same row with different superscripts differ ($P<.05$).

^{xyz}Means in the same row with different superscripts differ ($P<.10$).

TABLE 18

EFFECT OF SORGHUM GRAIN HYBRID
ON PRE-CECAL DIGESTION

Item	Y1	Y2	C1	C2	HY1	HY2	SE
Leaving ileum, g/d							
Chyme, liters	13.4	16.1	15.6	12.3	15.4	12.9	1.35
OM	2,119	2,186	2,556	2,078	2,142	1,949	189.1
Starch	874	761	1,165	865	782	779	178.6
Total N	54.1	55.8	59.4	49.6	59.0	52.9	2.83
Non-NH_3 N	52.8	54.6	58.2	48.8	58.0	51.9	2.70
Pre-cecal digestibility, %							
OM	65.2	63.8	57.5	65.6	64.8	66.9	2.94
Starch	77.0	77.9	69.5	76.4	79.6	76.9	3.79
Total N	53.1	52.0	48.8	57.0	49.2	54.4	2.24
Non-NH_3 N	54.2^{xyz}	53.0^{xyz}	49.8^{z}	57.8^{x}	50.2^{yz}	55.2^{xy}	2.13
Pre-cecal digestibility, % of total digestion							
OM	95.8^{xyz}	101.9^{xy}	87.7^{z}	94.1^{yz}	103.3^{x}	93.8^{yz}	3.48
Starch	95.3^{xy}	101.4^{x}	84.4^{z}	91.4^{yz}	95.0^{xy}	91.2^{yz}	4.02
Total N	95.7	102.0	92.7	99.6	104.0	93.8	3.38
Non-NH_3 N	96.6^{yz}	102.7^{xy}	93.4^{z}	100.0^{xyz}	104.7^{x}	94.2^{z}	3.24

^{abc}Means in the same row with different superscripts differ ($P<.05$).

^{xyz}Means in the same row with different superscripts differ ($P<.10$).

TABLE 19

EFFECT OF SORGHUM GRAIN HYBRID ON DIGESTION IN THE SMALL INTESTINE

Item	Y1	Y2	C1	C2	HY1	HY2	SE
Disappearance in the small intestine, g/d							
OM	1,057	727	640	1,009	1,110	751	166.1
Starch	357.0	244.3	163.7	350.0	331.5	131.6	151.81
Total N	70.0	73.1	70.2	70.4	78.8	54.6	5.88
Non-NH_3 N	67.2	70.2	67.2	67.4	76.0	52.2	5.89
Digestibility in the small intestine:							
% of entry							
OM	32.4	23.6	19.0	30.5	32.4	24.0	4.47
Starch	25.4	16.9	5.6	25.2	16.8	4.6	13.44
Total N	55.3	56.4	54.1	58.2	57.8	52.8	2.44
Non-NH_3 N	54.9	55.8	53.5	57.6	57.2	52.0	2.49
% of intake							
OM	18.0	12.4	11.0	16.3	19.0	12.6	2.71
Starch	9.9	7.3	4.6	8.7	9.7	3.1	4.08
Total N	62.0	62.8	60.5	61.0	69.1	47.9	5.33
Non-NH_3 N	59.5	60.3	58.0	58.4	66.6	45.8	5.33
% of total digestion							
OM	25.4	19.5	16.9	23.4	29.7	17.7	4.28
Starch	11.8	8.7	5.4	10.1	4.6	4.5	4.19
Total N	113.3^{y}	125.6^{xy}	116.0^{y}	108.1^{yz}	145.8^{x}	84.1^{z}	11.01
Non-NH_3 N	107.4^{y}	119.4^{xy}	109.5^{y}	102.8^{yz}	138.9^{x}	79.6^{z}	10.91

TABLE 20

EFFECT OF SORGHUM GRAIN HYBRID ON DIGESTION IN THE LARGE INTESTINE

Item	Y1	Y2	C1	C2	HY1	HY2	SE
Disappearance in the large intestine, g/d							
OM	152.6	43.7	454.1	236.5	2.1	252.2	132.75
Starch	133.5	-9.7	455.5	243.3	136.2	242.2	122.66
Non-NH_3 N	2.5	-1.3	4.3	.2	-2.4	3.8	2.01
Digestibility in the large intestine:							
% of entry							
OM	6.3	2.7	15.2	9.1	-5.9	12.8	5.94
Starch	1.4	-.1	36.8	18.2	-7.4	26.8	18.68
Non-NH_3 N	3.9	-3.2	7.0	-.1	-4.7	5.7	3.60
% of intake							
OM	2.7	.6	7.4	4.2	-.1	4.4	2.10
Starch	3.8	-.5	11.8	7.0	3.8	7.3	3.21
Non-NH_3 N	2.0	-1.2	3.6	.4	-2.0	3.0	1.73
% of total digestion							
OM	4.2	.8	12.3	5.9	.3	6.2	3.48
Starch	4.7	-1.0	15.6	8.6	5.1	8.8	4.14
Non-NH_3 N	3.4	-2.7	6.6	-.1	-4.7	5.8	3.24

^{abc}Means in the same row with different superscripts differ ($P<.05$).

^{xyz}Means in the same row with different superscripts differ ($P<.10$).

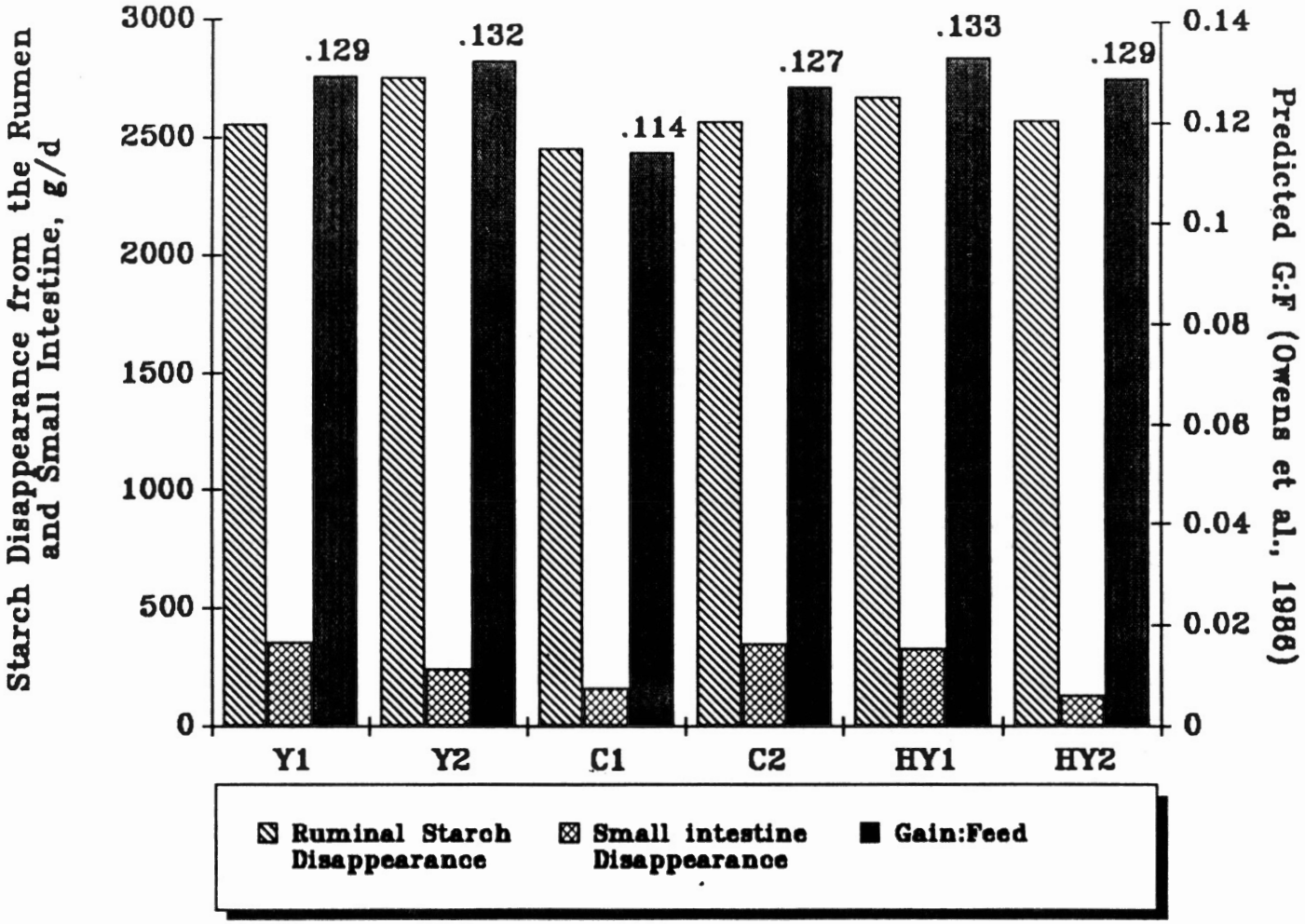

Figure 5. Starch Disappearance (g/d) from the Rumen and Small Intestine and Predicted Gain:Feed (G:F=.159*Ruminal Starch Digestibility + .227*Starch Digestion in the Small Intestine) for Sorghum Grain Hybrids

CHAPTER VII

SUMMARY

Experiment 1

A double L-shaped intestinal cannula was designed in an attempt to overcome some of the problems observed with other types of cannulae. The cannula was constructed from cyclopolyvinyl chloride water pipe and fittings. Despite rigid construction, connecting split cannula pieces with elastic castration bands provided some flexibility and permitted easy installation and removal. Mechanical disturbance to the cannula was reduced by exposing only a short cone shaped barrel to the exterior of the body surface.

Experiment 2

To compare the effect of sorghum grain hybrids and corn on site and extent of digestion, four current sorghum hybrids (yellow, cream, hetero-yellow and red and commercially purchased corn were dry rolled and fed in an 85% grain diet to Angus-Hereford steers (241 kg) equipped with permanent ruminal and duodenal and ileal double L type intestinal cannulae. Yellow (yel) has a homozygous yellow endosperm, with a yellow seed coat; whereas, cream and hetero-yellow (het-yel) have a heterozygous yellow endosperm with white and red seed coats, respectively. Red has a homozygous white endosperm with a red seed

coat. Diets were fed at 2% of body weight (DM basis) in a 5X5 Latin square. Total tract starch digestibility (%) was greater ($P<.05$) for corn (92.5) than for red (84.3), yel (84.3) and het-yel (82.9), but not greater than ($P>.10$) cream (87.9). Ruminal starch digestibility (%) was greater ($P<.10$) for corn (85.8) than for all sorghum hybrids (69.1). Pre-cecal starch digestibility (%) was greater ($P<.05$) for corn (90.6) than het-yel (76.2), red (74.8) and yel (74.1) but not different ($P>.10$) from cream (82.5). The small intestine tended to be a more important site of starch digestion (% of total tract digestion) for het-yel (11.0), red (10.4), and cream (9.8) than for corn (5.1) or yel (4.6). Ruminal escape of feed N (%) was greater ($P<.10$) for red (79.9) than het-yel (69.2), cream (66.5) and yel (66.1) while corn (53.6) was less than ($P<.10$) all sorghum hybrids. Pre-cecal non-NH_3 N (NAN) digestibility and total tract NAN digestibility were not altered ($P>.10$) by sorghum grain hybrid and corn . Sorghum hybrid altered site and extent of starch digestion and ruminal escape of feed N in cattle. Corn was more digestible than all sorghum grain hybrids except cream.

Experiment 3

Studies of ruminal dry matter disappearance in vitro (IVDMD) and gas production in vitro (GP), involving amyloglucosidase and yeast, were conducted to compare eight divergent current sorghum grain hybrids and maize. Chemical and physical characteristics of the grains also were described. Sorghums included two yellow (Y1 and Y2; homozygous yellow endosperm, with a yellow seed coat), two cream (C1 and C2; heterozygous yellow endosperm, with a white seed coat), two hetero-yellow (HY1 and HY2; heterozygous yellow, with a red seed coat), one

red (R; homozygous white endosperm, with a red seed coat) and one bird resistant (BR; white endosperm, with a brown seed coat containing condensed tannin) hybrids. Maize (29.7%) contained more ($P<0.05$) sodium chloride soluble protein (NaCl-N) than other grains except Y1 (26.7%). BR contained more pepsin insoluble nitrogen and less NaCl-N, and had smaller berries of greater density ($P<0.05$) than other grains. BR (26.9%) had lower ($P<0.05$) and maize (51.8%) had greater ($P<0.05$) IVDMD than other sorghum hybrids. Yellow hybrids were 1.9% more digestible than cream hybrids and 6.2% more digestible than hetero-yellow hybrids. Y1 (42.2), Y2 (42.2), C1 (421.0) and HY1 (41.9) had greater ($P<0.05$) IVDMD than HY2 (37.2), with C2 (40.8) being intermediate ($P>0.05$). BR and HY1 had greater ($P<0.05$) and maize (253.3) had less ($P<0.05$) 12-hour GP than other grains. The estimated first order rate constant for starch digestion was highest ($P<0.05$) for BR and lowest ($P<0.05$) for maize. The rate of starch degradation among sorghum hybrids of common endosperm and seed coat color differed, with C2, HY1 and Y1 tending to have a greater rate of GP than R, while HY2, C1 and Y2 tended to have a lower rate of GP than R. When hybrids with a yellow endosperm were averaged within endosperm and seed coat color no advantage was noted for homozygous or heterozygous yellow endosperm. However, sorghum grain with a yellow endosperm (homozygous or heterozygous) tended to have greater starch availability than R, and parental varieties altered starch availability within endosperm types.

Experiment 4

To compare the effect of two yellow (Y1 and Y2), two cream (C1 and C2) and two hetero-yellow (HY1 and HY2) sorghum grain hybrids on site

and extent of digestion sorghum grain was dry rolled and fed in an 81% grain diet to Angus-Hereford steers (342 kg) equipped with ruminal, duodenal and ileal double L type intestinal cannulae. Yellow grains had a homozygous yellow endosperm and a yellow seed coat,cream and hetero-yellow grains had a heterozygous yellow endosperm, with a white and red seed coat, respectively. Diets were fed at 1.85% of body weight (DM basis) in a 6x6 Latin square. Total tract OM digestibility (%) was greater ($P<.10$) for HY2 (71.4) and C2 (69.8) than for C1 (64.9), Y2 (62.8) and HY1 (62.6), but was not different ($P>.10$) from Y1 (67.9%). Total tract starch digestibility was correlated ($r=.80$; $P<.001$) to OM digestibility. Total tract non-NH_3 N (NAN) digestibility (%) was greater ($P<.05$) for HY2 (67.8) and C2 (67.0) than for C1 (62.0), Y2 (59.8) and HY1 (55.6), but was not different ($P>.10$) from Y1 (64.8). Ruminal starch digestion was negatively correlated ($r=-.46$; $P<.08$) to feed N flow to the duodenum. When ruminal starch digestion was expressed as a percent of total digestion, Y2 (95.3) was greater ($P<.10$) than Y1 (83.6), C2 (81.2) and C1 (79.0), but was not different from HY2 (90.7) or HY1 (90.5). Greater ($P<.10$) escape of feed N from ruminal degradation (%) was noted for HY1 (68.3) and Y2 (59.6) than for C2 (50.1) and HY2 (46.2), with C1 (58.0) and Y1 (57.9) not different from C2 or Y2. Pre-cecal starch digestibility averaged 76.2% and was more strongly correlated to ruminal starch digestibility ($r=.69$; $P<.01$) than to starch digestion in the small intestine ($r=.41$; $P=.12$). Microbial N flow to the duodenum was strongly correlated ($r=.88$; $P<.01$), while feed N flow to the duodenum was weakly correlated ($r=.17$; $P=.52$) to fractional NAN digestibility in the small intestine. Hybrids

differed in site and extent of NAN digestion but, no clear advantage was observed for homozygous versus heterozygous yellow endosperm.

General Observations

Experiments indicated that further research is needed to identify sorghum grain hybrids that have a feeding value comparable to corn. Sorghum hybrids with a yellow endosperm appear to be more digestible than hybrids with white endosperm; however, homozygous yellow endosperm was less digestible than heterozygous yellow endosperm in experiment 2. If sorghum hybrids with a homozygous yellow endosperm have an advantage over those with heterozygous yellow endosperm it would appear to be small based on results obtained in experiment 4. Perhaps higher feed intake would amplify the small differences in starch digestibility observed among hybrids in experiment 4. In vitro hybrids with yellow endosperm hybrids were more digestible than the single white endosperm hybrid included in the study. Reasons for much greater in vitro digestibility of some hybrids with yellow endosperm compared to others may be an important area for future research.

Differences in parental varieties probably result in differences among hybrids. While we have attempted to quantify differences between hybrids, these differences may have been confounded with berry size. The impact berry size may have on sorghum grain digestibility is unknown. Perhaps future research should partition various berry sizes from a single sorghum grain hybrid and compare digestive qualities of berries of different size, but common genetic background and growing environment.

LITERATURE CITED

Aguirre, E.D., A.L. Goetsch and F.N. Owens. 1984. Effects of moisture level of fermented corn and corn grain processing on digestion in beef animals fed high concentrate diets. J. Anim. Sci. 59(Suppl. 1):443.

AOAC. 1975. Official Methods of Analysis (12th edn.). Association of Official Analytical Chemists, Washington, D.C.

Arambel, M.J. and C.N. Coon. 1981. Effect of diatary protein on amino acids and microbial protein of duodenal digesta. J. Dairy Sci. 64:2201.

Armstrong, D.G. and R.R. Smithard. 1979. The fate of carbohydrates in the small and large intestines of the ruminant. Proc. Nutr. Soc. 38:283.

Ash, R.W. 1962. Gastro-intestinal re-entrant cannulae for studies of digestion in sheep. Anim. Prod. 4: 309-312.

Asquith, T.N., H. Mehansho, J.C. Rogler, L.G. Butler and D.M. Carlson. 1985. Induction of proline-rich protein biosynthesis in salivary glands by tannins. Fed. Proc. 44:1097.

Barry, T.N. and T.R. Manley. 1984. The role of condensed tannins in the nutritional value of Lotus pedunculates for sheep. 2. Quantitative digestion of carbohydrates and proteins. Br. J. Nutr. 51:493.

Benson, M.E., D.G. Ely, K.A. Dawson and T.J. Smith. 1984. Phenolic compounds effect on rumen microbes and in vitro digestibility. J. Anim. Sci. 59(Suppl. 1):417.

Bergen, W.G., D.B. Bates, D.E. Johnson, J.C. Waller and J.R. Black. 1982. Ruminal microbial protein synthesis and efficiency. In: F.N. Owens (Ed.) Protein requirements of Cattle: Symposium. Okla. State Univ. MP-109:99.

Bergen, W.G., D.B. Purser and J.H. Cline. 1968. Effect of ration on the nutritive quality of rumen microbial protein. J. Anim. Sci. 27:1497.

Bergen, W.G. and M.T. Yokoyama. 1977. Productive limits to rumen fermentation. J. Anim. Sci. 45:573.

Black, J.L. 1971. A theoretical consideration of the effect of preventing rumen fermentation on the efficiency of utilization of dietary energy and protein in the lamb. Br. J. Nutr. 25:31.

Brodrick, G.A. and J.H. Kang. 1980. Automated simultaneous determination of ammonia and amino acids in ruminal fluid and in vitro media. J. Dairy Sci. 63:64.

Brown, G.W., Jr., A.D. Tillman and R. Totusek. 1968. Digestibility, nitrogen retension and energy of sorghum grain and corn rations at three levels of intake. J. Anim. Sci. 27:170.

Burns, R.E. 1971. Methods for estimation of tannin in grain sorghum. Agron. J. 63:511.

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

Cole, N.A., R.R. Johnson and F.N. Owens. 1976a. Influence of roughage level and corn processing method on the site and extent of digestion by beef steers. J. Amin. Sci. 43:490.

Cole, N.A., R.R. Johnson and F.N. Owens. 1976b. Influence of roughage level and corn processing method on microbial protein synthesis by beef steers. J. Anim. Sci. 43:497.

Crawford, R.J. Jr., W.H. Hoover and L.L. Junkins. 1980. Effects of solids and liquid flows on fermentation in continuous cultures. II. Nitrogen partition and efficiency of microbial synthesis. J. Anim. Sci. 51:986.

Czerkawski, J.W. 1986. Degradation of solid feeds in the rumen: Spatial distribution of microbial activity and its consequences. In: L.P. Milligan, W.L. Grovum and A. Dobson. (Eds.). Control of Digestion and Metabolism in Ruminants. Pretice-Hall, Englewood Cliffs, NJ.

DeGregorio, R.M., R.E. Tucker, G.E. Mitchell, Jr. and W.W. Gill. 1982. Carbohydrate fermentation in the large intestine of lambs. J. Anim. Sci. 54:855.

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

Erfle, J.D., R.J. Baila, R.M. Teather, S. Mahadevan and F.D. Sauer. 1982. Effect of pH on fermentation characteristics and protein degradation by rumen micro organisms in vitro. J. Dairy Sci. 65:1157.

Faichney, G.J. 1986. The kenetics ofparticulate matter in the rumen. In: L.P. Milligan, W.L. Grovum and A. Dobson. (Eds.). Control of Digestion and Metabolism in Ruminants. Pretice-Hall, Englewood Cliffs, NJ.

Fenton, T.W. and M. Fenton. 1979. An improved procedure for the determination of chromic oxide in feed and feces. Can. J. Anim. Sci. 59:631.

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

Froetschel, M.A., H.E. Amos, J.J. Evans, W.J. Croom, Jr. and W.M. Hagler, Jr. 1989. Effects of a salivary stimulant, slaframine, on ruminal fermentation, bacterial protein synthesis and digestion in frequently fed steers. J. Anim. Sci. 67:827.

Galyean, M.L., D.G. Wagner and F.N. Owens. 1979. Level of feed intake and site and extent of digestion of high concentrate diets by steers. J. Anim. Sci. 49:199.

Galyean, M.L., D.G. Wagner and R.R. Johnson. 1976. Site and extent of starch digestion in steers fed processed corn rations. J. Anim. Sci. 43:1088.

Ganev, G., E.R. Orskov and R. Smart. 1979. The effect of roughage or concentrate feeding and rumen retention time on total degradation of protein in the rumen. J. Agric. Sci. (Camb.) 93:651.

Goering, H.K. and P.J. Van Soest. 1970. Forage fiber analysis (apparatus, reagents, procedures and some applications). Agric. Handbook No. 379, USDA, ARS.

Goetsch, A.L., M.A. Funk, F.N. Owens and K.B. Poling. 1984. Roughage for beef heifers fed rolled milo diets. Okla. Agric. Exp.Sta. Res. Rep. MP-116:204.

Goetsch, A.L. and F.N. Owens. 1984. Ileal starch administration and diatary nitrogen level for steer calves fed high concentrated diets. Okla. Agric. Exp. Sta. Res. Rep. MP-116:240.

Goetsch, A.L. F.N. Owens, C.E. Kautz and K.W. Milliner. 1983. Effect of ruminal pH alteration on digestion in steers fed a high concentrate diet. Okla. Agric Exp. Sta. Res. Rep. MP-114:10.

Goldy, G., J. Riley and K. Bolsen. 1987. Comparative feeding value of grain sorghum and corn in beef cattle diets. Kansas Feeders Day Report, p. 1.

Hagerman, A.E. and L.G. Butler. 1981. The specificity of proanthocyanidin-protein interactions. J. Bio. Chem. 256:4494.

Harbers, L.H. and A.B. Davis. 1974. Digestion of sorghum grain endosperm in the rat and pig observed by scanning electron microscopy. J. Anim. Sci. 39:1099.

Hecker, J.F. 1974. Experimental Surgery on Small Ruminants, p. 99 and p. 126. London: Butterworths and Co. Ltd.

Hembry, F.G., W.A. Phonoler and R.L. Preson. 1975. Utilization of nitrogen from soybean meal, casein, zein and urea by mature sheep. J. Nutr. 105:267.

Hibberd, C.A., D.G. Wagner, R.L. Hintz and D.D. Griffin. 1985. Effect of sorghum grain variety and reconstitution on site and extent of starch and protein digestion in steers. J. Anim. Sci. 61:702.

Hibberd, C.A., D.G. Wagner, R.L. Schemm, E.D. Mitchell, Jr., R.L. Hintz and D.E. Weibel. 1982a. Nutritive characteristics of different varieties of sorghum and corn grain. J. Anim. Sci. 55:665.

Hibberd, C.A., D.G. Wagner, R.L. Schemm, E.D. Mitchell, Jr. D.E. Weibel and R.L. Hintz. 1982b. Digestibility characteristics of isolated starch from sorghum and corn grain. J. Anim. Sci. 55:1490.

Hinman, D.D. and R.R. Johnson. 1974a. Influence of processing methods on digestion of sorghum starch in high concentrate beef cattle rations. J. Anim. Sci. 39:417.

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

Hoseney, R.C., A.B. Davis and L.H. Harbers. 1974. Pericarp and endosperm structure of sorghum grain shown by scanning electron microscopy. Cereal Chem.

Hume, I.D. 1974. The proportion of diatary protein escaping degradation in the rumen of sheep fed on various protein concentrations. Aust. J. Agric. Res. 25:155.

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

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

Huntington, G.B., R.L. Prior and R.A. Britton, 1891. Glucose and lactate absorption and metabolic interrelationships in steers changed from low to high concentrate diets. J. Nutr. 111:1164.

Issacson, H.R., F.C. Hinds, M.P. Bryant and F.N. Owens. 1975. Efficiency of energy utilization by mixed rumen bacteria in continuous culture. J. Dairy Sci. 58:1645.

Johnson, A. R. Harwitz and N. Kretchmer. 1977. Adaptation of rat pancreatic amylase and chymotrpsinogen and changes in diet. J. Nutr. 107:87.

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

Kennedy, P.M. and L.P. Milligan. 1980. The degradation and utilization of endogenous urea in the gastro intestinal tract of ruminants. A review. Can J. Anim. Sci. 60:205.

Kim, Y.K. and F.N. Owens. 1985. Starch digestion by feedlot cattle: Influence of roughage and intake level and particle size. Okla. Agric. Exp. Sta. Res. Rep. MP-117:298.

Komarek, R.J. 1981. Intestinal cannulation of cattle and sheep with a T-shaped cannula designed for total digesta collection without externalizing digesta flow. J. Anim. Sci. 53: 796-802.

Laughren, L.C. and A.W. Young. 1979. Duodenal nitrogen flow in response to increasing diatary crude protein in sheep. J. Anim. Sci. 49:211.

Leach, H.W. and T.J. Schoch. 1961. Structure of the starch granule II. Action of various amylases on granular starch. Cereal Chem 38:34.

Lichtenwalner, R.C., E.B. Ellis and L.W. Rooney. 1978. Effect of incremental dosages of the waxy gene of sorghum on digestibility. J. Anim. Sci. 46:1113.

MacRae, J.C. and D.G. Armstrong. 1968. Enzyme methods for determination of alpha-linked glucose polymers in biological materials. J. Sci. Food Agric. 19:578.

MacRae, J.C. and Wilson, S. 1977. The effect of various forms of gastrointestinal cannulation on digestive measurements in sheep. Br. J. Nutr. 38: 65-71.

Mahadevam, S., J.D. Erfte and F.D. Saver. 1980. Degredation of soluble and insoluble proteins by Bacteroides Amylophilus protease and by rumen microorganisms. J. Anim. Sci. 50:723.

Mason, V.C., M.P. Narang, J.C. Ononiwu and P. Kessconk. 1977. The relationship between nitrogen metabolism in the hind-gut and nitrogen excretion. In. Second International Symposium on Protein Metabolism and Nutrition. Center of Agricultural Publishing and Documentation. Wagening En.

Maxson, W.E., R.L. Shirley, J.E. Bertrand and A.Z. Palmer. 1973. Energy values of corn, bird-resistant and non-bird-resistant sorghum grain in rations fed to steers. J. Anim. Sci. 37:1451.

McAllan, A.B. and R.H. Smith. 1974. Carbohydrate metabolism in the ruminant. Br. J. Nutr. 31:77.

McAllan, A.B. and R.H. Smith. 1976. Effect of diatary nitrogen source on carbohydrate metabolism in the rumen of the young steer Br. J. Nutr. 36:511.

McAllan, A.B. and R.H. Smith. 1977. Some effects of variation in carbohydrate and nitrogen intakes on the chemical composition of mixed rumen bacteria from young steers. Br. J. Nutr. 37:55.

McCollough, R.L. and B.E. Brent. 1972. Digestibility of eight hybrid sorghum grains and three hybrid corns. Kansas Agr. Exp. Sta. Bull. 557:27.

McCollough, R.L., C.L. Drake and G.M. Roth. 1972. Feedlot performance of eight hybrid sorghum grains and three hybrid corns. Kansas Agric. Exp. Sta. Progress Rep. Bull. 557:21.

McDougall, E.I. 1948. Studies on ruminant saliva. 1. The composition and output of sheep's saliva. Biochem. J. 43:99.

McGilliard, A.D. 1982. Surgical techniques, advances and cautions. In. F.N. Owens (Ed.) Protein requirements for cattle: Symposium. Okla. State Univ. MP-109:31.

McLeod, M.N. 1974. Plant tannins - Their role in forage quality. Nutr. Abstr. Rev. 44:803.

McNeill, J.W. G.D. Potter and J.K. Riggs. 1971. Ruminal and post ruminal carbohydrate utilization in steers fed processed sorghum grain. J. Anim. Sci. 33:1371.

McNeill, J.W., G.D. Potter, J.K. Riggs and L.W. Rooney. 1975. Chemical and physical properties of processed sorghum grain carbohydrates. J. Anim. Sci. 40:335.

Mehansho, H., L.G. Butler and D.M. Carlson. 1987. Dietary tannins and salivary proline-rich proteins: Interactions, induction and defense mechanism. Ann. Rev. Nutr. 7:423.

Mehansho, H., A.E. Hagerman, S. Clements, L. Butler, J. Rogler and D.M. Carlson. 1983. Modulation of proline-rich protein biosynthesis in the rat parotid glands by sorghums with high tannin levels. Proc. Natl. Acad. Sci. USA. 80:3948.

Mehrez, A.Z. and E.R. Orskov. 1976. Rates of rumen fermentation in relation to ammonia concentration. Proc. Nutr. Soc. 35:40A.

Miller, G.D., C.W. Deyoe, T.L. Walter and F.W. Smith. 1962. Variations in protein levels in Kansas sorghum grain. Agron. J. 56:302.

Miller, F.R., R.S. Lowery, W.G. Monson, G.W. Burton and H.J. Cruzado. 1972. Estimation of dry matter digestibility differences in grain of some sorghum bicolor (L.) Moench varieties. Crop Sci. 12:563.

Mole, S. and P.G. Waterman, 1985. Stimulatory effects of tannins and cholic acid on tryptic hydrolysis of proteins: Ecological implications. J. Chem Ecol. 11:1323.

Muindi, P.J. and S. Thomke. 1981. The nutritive value for rats of high- and low-tannin sorghum treated with magadi soda. J. Sci. Food Agric. 32:139.

Muindi, P.J., S. Thomke and R. Ekmon. 1981. Effect of magadi soda treatment on the tannin content and in vitro nutritive value of grain sorghums. J. Sci. Food Agric. 32:25.

Nakamure, T., T.J. Klopfenstein and R.A. Britton. 1989. Digestibility of heated and unheated protein sources. ASAS Midwestern Section Abstracts, p 153.

Neudoerffer, T.S., P.A. Leadbeater, F.D. Horney and H.S. Bayley. 1971. The influence of level of grain intake on protein digestion in the intestine of cattle. Br. J. Nutr. 25:343.

Nicholson. J.W.G. and J.D. Sutton. 1969. The effect of diet composition and level of feeding on digestion in the stomach and intestines of sheep. Br. J. Nutr. 23:585.

Nishimutta, J.R., L. B. Sherrod and R.D. Furs. 1969. Digestibility of regular waxy and white sorghum grain ration by sheep. J. Anim. Sci. 28:860 (Abstr).

Nolan, J.V., B.W. Norton and R.A. Leng. 1973. Nitrogen cycling in sheep. Proc. Nutr. Soc. 32:93.

Norris, J.R. and L.W. Rooney. 1970. Wet-milling properties of four parents and their hybrids. Cereal Chem. 47:64.

NRC. 1984. Nutrient Requirements of Beef Cattle. National Research Council - National Academy of Science, Washington, D.C.

Obuchowski, W. and W. Bushak. 198Q. Wheat hardness: Effects of debranning and protein content. Cereal Chem. 57:426.

Oltjen, R.R., A.S. Kozak, P.A. Putnam and R.P. Lehmann. 1967. Metabolism, plasma amino acid and salivary studies with steers fed corn, wheat, barley and milo all-concentrate rations. J. Anim. Sci. 26:1415.

Orskov, E.R. 1977. Capacity for digestion and effects of composition of absorbed nutrients on animal metabolism. J. Anim. Sci. 45:600.

Orskov, E.R. 1982. Protein Nutrition in Ruminants. Academic Press, New York, N.Y.

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

Orskov, E.R., C. Fraser and R.N.B. Kay. 1969. Diatary factors influencing the digestion of starch in the rumen and small and large intestine of early weaned lambs. Br. J. Nutr. 23:217.

Orskov, E.R., C. Fraser, V.C. Mason and S.O. Mann. 1970. Influence of starch digestion in the large intestine of sheep on caecal fermentation, caecal microflora and caecal nitrogen excretion. Br. J. Nutr. 24:671.

Orskov, E.R., C. Fraser and I McDonald. 1971. Digestion of concentrates in sheep. 3. Effects of rumen fermentation of barley and maize diets on protein digestion. Br. J. Nutr. 26:477.

Osman, H.F., B. Theurer, W.H. Hale and S.M. Mehen. 1970. Influence of grain processing on in vitro enzymatic starch digestion of barley and sorghum grain. J. Nutr. 100:133.

Owens, F.N. and W.G. Bergen. 1983. Nitrogen metabolism of ruminant animals: Historical perspective, current understanding and future implications. J. Anim. Sci. 57(Suppl. 2):498.

Owens, F.N. and H.R. Isaacson. 1977. Ruminal microbial yeilds: Factors influencing synthesis and bypass. Fed. Proc. 36:198.

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

Pomeranz, Y. 1986. Comparison of screening methods for indirect determination of sorghum hardness. Cereal Chem. 63:36.

Potter, G.D., J.W. McNeill and J.K. Riggs. 1971. Utilization of processed sorghum grain proteins by steers. J. Anim. Sci. 32:540.

Price, M.L., S. VanScoyoc and L.G. Butler. 1978. A critical evaluation of the vanillin reaction as an assay for tannin in sorghum grain. J. Agric. Food Chem. 26:1214.

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

Prigge, E.C., R.R. Johnson, F.N. Owens and D.E. Williams. 1976. Utilization of nitrogen from ground high moisture and dry corn by ruminants. J. Anim. Sci. 43:705.

Remillard, R.L. and D.E. Johnson. 1984. Starch digestion in the bovine small intestine with and without buffer and amylase infusion. J. Anim. Sci. 59(Suppl. 1):444.

Robbins, C.T., S. Mole, A.E. Hagerman and T.A. Hanley. 1987. Role of tannin in defending plants against ruminants: Reduction in dry matter digestion. Ecology 68:1606.

Rooney, L.W. and F.R. Miller. 1982. Variation in the structure and kernal characteristics of sorghum. Proc. Sorghum Grain Quality Symp. pp. 143-161. Int. Crop Res. Inst. for the Semi-arid Tropics, Hyderabad, India.

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

Rooney, L.W. and J.K. Riggs. 1971. Utilization of sorghum. In: Grain Sorghum Research in Texas. PR-2945 and 2946. Texas Agric. Exp. Sta. College Station.

Russell, J.R., A.W. Young and N.A. Jorgensen. 1981. Effect of diatary corn starch intake on ruminal, small intestinal and large intestinal starch digestion in cattle. J. Anim. Sci. 52:1170.

Rust, S.R. 1983. Associative effects in the ruminant animal. Ph.D. Dissertation, Oklahoma State University, Stillwater.

Rust, S.R., F.N. Owens, D.R. Gill and R.W. Fent. 1979. Corn moisture, protein concentration and Rumensin and digestion by feedlot steers. Oklahoma Agric. Exp. Sta. MP-104:55.

Saba, W.J., W.H. Hale and B. Theurer. 1972. In vitro rumen fermentation studies with a bird resistant sorghum grain. J. Anim. Sci. 35:1076.

Saba, W.J., W.H. Hale, F. Hubbert, Jr., J. Kiernat and B.Taylor. 1964. Digestion of milo and barley by cattle. J. Anim. Sci. 23:533.

Samford, R.A., J.K. Riggs, D.G. Potter, L.W. Rooney and J.Coon. 1970. In vitro and in vivo digestibility of sorghum grain varieties. Texas Agric. Exp. sta. Prog. Rep. PR-2784.

Sandstedt, R.M., D. Strahan, S. Ueda and R.C. Abbot. 1962. The digestibility of high-amylose corn starches compared to that of other starches. The apparent effect of the ae gene on susceotibility to amylase action. Cereal Chem. 39:123.

SAS. 1988. Procedures Guide for Personal Computers. SAS Institute, Cary, North Carolina.

Satter, L.D. and L.L. Slyter. 1974. Effect of ammonia concentration on rumen microbial protein production in vitro. Br. J. Nutr. 32:199.

Schake, L.M., A Driedger, J.K. Riggs and D.N. Clamme. 1976. Corn and grain sorghum evaluations for beef cattle. J. Anim. Sci. 43:959.

Seckinger, H.L. and M.J. Wolf. 1973. Sorghum protein ultrastructure as it relates to composition. Cereal Chem. 50:455.

Siddons, R.C. 1968. Carbohydrase activities in the bovine digestive tract. Biochem. J. 108:839.

Spicer, L.A., C.B. Theurer, J. Sowe and T.H. Noon. 1986. Ruminal and post-ruminal utilization of nitrogen and starch from sorghum grain-,corn- and barley-based diets by beef steers. J. Anim. Sci. 65:521.

Steel, R.G. and J.H. Torrie. 1980. Principles and Procedures of Statistics. McGraw-Hill Inc. New York.

Streeter, M.N., D.G. Wagner, C.A. Hibberd, E.D. Mitchell, Jr. and J.W. Oltjen. 1989a. Effect of variety of sorghum grain on digestion and availability of dry matter and starch in vitro. Anim. Feed Sci. and Tech. submitted.

Streeter, M.N., D.G. Wagner, C.A. Hibberd and F.N. Owens. 1989b. The effect of sorghum grain variety on site and extent of digestion in beef heifers. J. Anim. Sci. Submitted.

Streeter, M.N., D.G. Wagner, C.A. Hibberd and F.N. Owens. 1989c. Comparison of corn and four sorghum grain hybrids: Site and extent of digestion in beef steers. J. Anim. Sci. submitted.

Streeter, M.N., D.G. Wagner, C.A. Hibberd, F.N. Owens and F.T. McCollum. 1989d. A double L intestinal canuala for cattle. Can. J. Anim. Sci. Submitted.

Streeter, M.N., D.G. Wagner, C.A. Hibberd, F.N. Owens, E.D. Mitchell, Jr. and J.W. Oltjen. 1989e. The effect of sorghum grin hybrid and corn on starch and dry matter digestion in vitro. Anim. Feed Sci. and Tech. submitted.

Streeter, M.N., D.G. Wagner, F.N. Owens and C.A. Hibberd. 1989f. Combinations of high moisture harvested sorghum grain and dry rolled corn: Effects on site and extent of digestion in beef heifers. J. Anim. Sci. accepted.

Sullins, R.D. and L.W. Rooney. 1974. Microscopic evaluation of the digestibility of sorghum lines that differ in endosperm characteristics. Cereal Chem. 51:134.

Sutton, J.D. 1971. Carbohydrate digestion and glucose supply in the gut of the ruminant. Proc. Nutr. Soc. 30:243.

Tagari, H., Y. Henis, M. Tamir and R. Volcani. 1965. Effect of carob pod extract on cellulolysis, proteolysis, deamination and protein biosynthesis in an artificial rumen. App. Microbio. 13:437.

Tanksley, T.D. and D.A. Knabe. 1984. Ileal digestibilities of amino acids in pig feeds and their use in formulating diets. In: W. Harresign and D.J. A. Cole (Ed.) Recent Advances in Animal Nutrition. pp. 75-96. Butterworth's, London.

Teeter, R.G., R.N. Owens and T.L. Mader. 1984. Ytterbium chloride as a marker for particulate matter in the rumen. J. Anim. Sci. 58:465.

Theurer, C.B. 1979. Microbial protein synthesis as influenced by diet. In Regulation of Acid-Base Balance. Piscataway, N.J.: Church and Dwight Co.

Uden, P., P.E. Colucci and P.J. VanSoest. 1980. Investigation of chromium, cerium and cobalt as markers in digesta. Rate of passage studies. J. Sci. Food Agric. 31:625.

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

Veira, D.M. and G.K. Macleod. 1980. Effects of physical form of corn and urea supplementation on performance of male Holstein calves. Can J. Anim. Sci. 60:931.

Wagner, D.G. 1984. Influence of variety on starch, protein and tannin content and utilization of sorghum grain. Proc. Feed Grains Util. Sump. Lubbock, Tx. pp 36-57.

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

Waldo, D.R. and H.K. Goering. 1979. Insolubility of grain protein in ruminant feed by four methods. J. Anim. Sci. 49:1560.

Walker, J.W., Stuth, J.W., Heitschmidt, R.K. and Downhower, S.L. 1985. A new esophageal plug. J. Range Manage. 38: 185-187.

Wall, J.S. and L.W. Paulis. 1978. Corn and sorghum grain proteins. In: Y. Pomeranz (Ed.) Advances in Cereal Science and Technology II. pp 135-219. Amer. Assoc. Cereal Chem., St. Paul, MN.

Wall, J.S. and W.M. Ross. 1970. Sorghum Production and Utilization. AVI Publishing Company, Westport, CT. pp 121-140.

Watson, S.A., E.H. Sanders, R.D. Wakely and C.B. Williams. 1955. Peripheral cells of the endosperms of grain sorghum and corn and their influence on starch purification. Cereal Chem. 32:165.

Weakley, D.C. 1983. Influence of roughage level, ruminal pH and ammonia concentration on ruminal protein degradation and microbial protein synthesis in cattle. Ph.D. Dissertation. Oklahoma State University.

Weller, R.A. and F.V. Gray. 1953. The passage of starch through the stomach of the sheep. J. Exp. Biol. 31:40.

Wenham, G. and R.S. Wyburn. 1980. A radiological investigation of the effects of cannulation on intestinal motility and digesta flow in sheep. J. Agric. Sci. (Camb.) 95:539.

Wohlt, J.E., C.J. Sniffen and W.H. Hoover. 1973. Measurement of protein solubility in common feedstuffs. J. Dairy Sci. 56:1052.

Zinn, R.A., L.S. Bull and R.W. Hemken. 1981. Degradation of supplemental proteins in the rumen. J. Anim. Sci. 52:857.

Zinn, R.A. and F.N. Owens. 1980. Influence of roughage level and feed intake level on digestive function. Okla. Agric. Exp. Sta. Res. Rep. MP-107:150.

Zinn, R.A. and F.N. Owens. 1981. Influence of level of feed intake on digestive function: I. Nitrogen metabolism. Okla. Agr. Exp. Sta. Res. Rep. MP-108:146.

Zinn, R.A. and F.N. Owens. 1982. Predicting net uptake of nonammonia nitrogen from the small intestine. In. F.N. Owens (Ed.) Protein Requirements of Cattle: Symposium. Okla. State Univ. MP-109:133.

Zinn, R.A. and F.N. Owens 1983a. Influence of feed intake level on site of digestion in steers fed a high concentrate diet. J. Anim. Sci. 56:471.

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

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

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