INFLUENCE OF PROCESSING METHOD ON THE SITE AND EXTENT OF MILO STARCH DIGESTION IN RUMINANTS

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CHAPTER I

INTRODUCTION

The processing of cereal grains for beef cattle rations has been studied widely in recent years. Most rations presently being fed to feedlot cattle routinely contain 80-90% cereal grain and, therefore, supply the major source of energy for fattening cattle. Research reports have shown that several processing techniques for cereal grains have improved the efficiency of utilization of these grains for growth and fattening. The digestibility of the ration and the rates of gain were increased by grain processing in some experiments. Others have shown a decreased feed intake but increased feed efficiency due to processing.

This improvement in efficiency may be due to a change in the pattern of rumen fermentation and/or an increased digestion of the starch portion of the ration. Since the major source of energy from cereal grains is derived from the starch, the site and extent of digestion of starch in cattle fed high concentrate rations may be related to the increased feed efficiency. The ruminant digests starch at two sites, the first being microbial fermentation in the rumen, and secondly, degradation in the intestinal tract. Should some starch escape the ruminal digestion, enzymatic digestion in the small intestine becomes important. The capacity of this second system may be limited. In addition, starch may be fermented by

microorganisms in the cecum and large intestine, should any starch reach the lower intestinal tract. In most rations almost all the ingested starch is digested by the animal, but the site of digestion in the digestive tract may vary with the method by which the grain was prepared. The literature indicates that the amount of starch escaping ruminal fermentation is variable. Therefore, this experiment was conducted to study the influence of grain processing on the site and extent of starch digestion in high milo rations.

CHAPTER II

REVIEW OF LITERATURE

Importance and Structure of Starch

The expansion of feed grain production and large feedlots in the southwest have resulted in large amounts of cereal grain in rations for fattening cattle. Cereal grains commonly comprise up to 90% of the ration for finishing cattle. Methods of improving the efficiency of utilization of these grains are of great economic importance to the cattle feeder. Various methods of processing these cereal grains have been studied.

Most cereal grains contain about 70-80% starch (Rooney and Clark, 1968; Greenwood, 1970) as the major energy source. The endosperm of the cereal grain is primarily starch granules imbedded in a proteinaceous framework (Graeza, 1965; Greenwood, 1970). The storage of starch in the granular form is a convenient method since starch is insoluble in water despite the fact that the starch molecule is highly hydroxylated and therefore very hydrophilic (Greenwood, 1970; Badenhuizen, 1965).

The starch granule is composed of linear and branched chain starch molecules associated by hydrogen bonding, either directly or through water hydrate bridges, to form radially oriented micelles or crystalline areas. The overall strength of the micellar network is

dependent upon the degree of association and molecular arrangement, (Leach, 1965). All starches, when grown under natural conditions show a layered or shell structure, (Badenhuizen, 1965).

The layers observed in starch granules are made up of two forms of starch molecules, amylose and amylopectin. The amylose and amylopectin molecules are intricately arranged and are held in this manner by hydrogen bonding, (Pazur, 1965). Amylose consists of a linear polymer of glucose units joined by α-(1-4) linkages to yield chains of several hundred glucose units. Amylopectin is a branched chain structure ranging from several thousand to millions of glucose units, (Pazur, 1965). Two types of linkages α-(1-4) and α-(1-6) have been definitely established for amylopectin. The α-(1-6) linkage gives rise to branch points in the molecule. Each branch of the amylopectin molecule contains up to twenty to thirty α-glucose units (Pazur, 1965; Greenwood, 1970; Wolfrom and Khadem, 1965). These authors also found that the ratio of amylose to amylopectin varied in different starches. However, most cereal starches contain about 25% amylose. Starches containing as much as 60% amylose have been found while others contain almost 100% amylopectin. The high amylose starches have been shown to be resistant to amylolytic digestion, (Sandstedt et al., 1962). Amylose in a pure form is found in a α-helical form and has a high degree of hydrogen bonding, (Wolfrom and Khadem, 1965). High amylopectin starches on the other hand are quite susceptable to amylolytic digestion, (Leach and Schoch, 1961; Hinders and Eng, 1970). Leach and Schoch (1961) listed the following starches in order of ease of digestion by amylases: waxy maize, waxy sorghum, sorghum, corn,

wheat, potato, high amylose-corn.

Gelatinization of Starch

The ease of degradation or susceptibility of starch granules to enzymatic attack is of importance considering that the starch of cereal grains constitutes a large portion of the diet for livestock. Starch granules exhibit a limited capacity for absorbing cold water and swelling reversibly, (Leach, 1965; Greenwood, 1970). When an aqueous suspension of starch is heated, reversible swelling occurs until the gelatinization temperature is reached. The temperature of gelatinization is a range of approximately $10^{o}C$ for most starches and varies with species of starch and degree of molecular association, (Greenwood, 1970; Rooney and Clark, 1968; Leach, 1965). The swelling of the granule weakens the micellar structure by disrupting the hydrogen bonds and results in loss of crystalline structure and development of cracks in the granule. The phenomena just described is termed gelatinization. Gelatinization is believed to begin in the more accessible and amorphous intermicellar areas of the granule where the bonding is the weakest. Gelatinization is further defined as damage to the starch granule by pressure, heat, shear or strain and moisture (Anstaett et al., 1969; Sandstedt and Mattern, 1960; Sullivan and Johnson, 1964). Starch gelatinization has been measured by microscopic structure, (Reeve and Walker, 1969), proton magnetic resonance, (Jaska, 1971), digestion by alpha-amylase, (Sandstedt and Mattern, 1960), congo red staining and susceptibility to beta-amylase, (Anstaett et al., 1969). Other indirect methods such as in vitro gas production and digestion by rumen microorganism

will be discussed later.

Enzymatic Degradation of Starch

The differences in digestion of starch as related to type of starch and degree of gelatinization must be examined. Leach and Schoch (1961) studied various raw starches and suggested that cereal starches may have a porous granule structure accessible to enzymes, while other starches are less permeable. Amylolytic digestion of raw cereal starches was observed to cause extensive erosion and fragmentation of corn and sorghum starches. The gelatinization of cereal starches (Badenhuizen, 1965) caused fragmentation of the starch granule and allowed access of amylases, resulting in both internal and external disintegration of the starch granule. Raw starches are more resistant to amylolytic digestion than cooked starches, (Leach and Schoch, 1961; Sandstedt and Mattern, 1960; Schwimmer, 1945). The difference between enzymatic hydrolysis of raw and cooked starch seems to be that of rate, (Schwimmer, 1945). Sandstedt and Mattern, (1960) determined that the rate of digestion was dependent upon the accessibility of the starch molecule to the enzyme. Damaged starch is readily and rapidly digested by the amylases, whereas the native starch granule is markedly more resistant to digestion.

The rapid and complete in vitro conversion of cooked starch to sugars requires two distinct enzymes, alpha-amylase and beta-amylase (Balls and Schwimmer, 1944). These authors also observed that a mixture of hog pancreatin and maltase would digest raw starch but at a slower rate than cooked starch. This mixture would digest starch

at a much faster rate than pancreatin alone, which is primarily an alpha-amylase (Greenwood, 1970). The action of alpha-amylase is a random degradation of α-(1-4) linkages of starch. Beta-amylase, which hydrolyses α-(1-4) glucosidic linkages to split maltose units from the non-reducing end of starch molecules is not present in animal tissue and is found only in higher plants. The hydrolases capable of hydrolysing α-(1-6) or α-(1-4) linkages have been discovered in microorganisms and animal tissue. This enzyme brings about a complete hydrolysis of starch directly to α-D-glucose (Pazur, 1965). Nasr (1950) identified an alpha-amylase in rumen bacteria and observed that production of this enzyme was stimulated by the presence of starch in the rumen. This observation was previously observed by VanDer Wath (1948), where starch, fed to a sheep on a diet of flaked maize, was digested at a faster rate than when fed to sheep not on a starch diet. Cooked starch was also digested by rumen microorganisms faster than raw starch. Starch digesting microorganisms are present in the rumen under most feeding regimes and possess the ability for rapid growth in response to the feeding of diets high in starch. This is likely the response observed by these authors when cereal grains were fed to sheep not adapted to starch.

Feeding Value of Processed Cereal Grain

The processing of cereal grains is accomplished by many methods. A reduction in particle size by dry rolling or grinding, hydrothermal treatment with moisture and heat, usually steam, and dry heat treatments are presently being used. The changes in animal performance and <u>in vitro</u> evaluations as influenced by these processing

methods are discussed in the following pages.

The hydrothermal processing of cereal grains has resulted in various responses. Wagner, Schneider and Renbarger (1970) found that steam flaking increased feed efficiency over dry rolled milo, but that increasing length of steaming time had no influence on animal performance. Steam pressure cooking milo increased the gelatinization of the starch granules (Anstaett and Pfost, 1969). Animal response was not different for steers fed popped, or pressure cooked and steam flaked milo, (Garrett, 1968). Johnson, Matsushima and Knox (1968) found that steam rolling corn to produce a thin flake increased starch modification and the utilization of the grain by steers. Steam flaking of milo (Buchanan-Smith, Totusek and Tillman, 1968; Schuh, 1970) increased feed efficiency over steam rolling milo; however, Taylor et al. (1961) found no difference in rate of gain or feed efficiency for steers fed steam rolled or dry ground milo. Hale et al. (1966) compared steam flaked and dry rolled milo and barley for steers and found increased grain and feed intake for the steam flaked grains. Feed efficiency was improved with the steam flaked milo but not with the steam flaked barley.

Comparison of the feeding value of various grains has resulted in some confusion in interpretation of the relative value of such grains as wheat, corn, milo and barley. Barley and milo were shown to have the same feeding value when fed to steers as ground or steam flaked grain (Garrett, 1965; Hale et al., 1966). However, other trials (Saba et al., 1964; Hubbert et al., 1962; Taylor et al., 1961) have shown that both steam flaked and dry rolled barley promoted greater feed efficiency than did milo prepared in the same

manner. The digestibilities of dry matter, protein, starch and NFE were greater for barley than for milo when fed to steers in rations of greater than 80% grain (Keating et al., 1965). Expanded corn had a greater digestibility than ground corn and resulted in a faster rate of gain (Haenlein et al., 1962).

Oltjen, Putman and Davis (1965) and Brethour and Duitsman (1966) found wheat to be undesirable when fed as 100% of the grain in a ration fed to steers. When fed rations of 60% corn and 30% wheat, steers made faster gains than when fed rations of 30% corn and 60% wheat (Oltjen et al., 1965). No differences were found between milo and corn (Brown et al., 1968) in the extent of digestion of the proximate fraction of rations fed to steers at varying levels of grain intake.

Using milo treated with moist heat followed by flaking increased the digestibility of the NFE fraction of the ration by 16.2% over the use of dry rolled milo (Husted et al., 1968) while Keating et al. (1965) demonstrated that cooking milo in water also increased the digestibility of the NFE. Brethour (1966) observed no difference in performance of cattle fed fine rolled and course rolled milo; however, Stevens (1971) found that grinding milo very fine increased the starch digestion of a 50% milo ration. Parrott et al. (1969) showed no differences between digestibilities of the proximate fractions or the total digestible nutrients of rations containing steam flaked or dry rolled barley. In a second trial the same results were obtained for rations containing steam flaked, dry rolled or steam rolled barley. Steam rolling barley improved feeding value by 16% over dry rolling barley in tests conducted by

Hubbert et al. (1962) and Taylor et al. (1961) and resulted in faster gains for steers (Taylor et al., 1961; Hale et al., 1966).

Since starch is the major component of the NFE in cereal grains, it appears that moist heat and flaking must improve the digestibility of the starch fraction of the ration. Steam flaking of milo (Husted et al., 1968), corn (Johnson et al., 1968), barley and milo (Hale et al., 1966; Keating et al., 1965) improved the digestibility of the NFE portion of the ration. The digestibility of non-protein organic matter (Buchanan-Smith et al., 1968) and starch (Holmes, Drennan and Garrett, 1970; McNeill, 1971) was improved by steam flaking milo. However, dry heat processing of milo (McNeill, 1971) did not improve starch digestion when compared to dry ground milo.

In Vitro Evaluation of Grain Processing

The first exposure of starch to digestion takes place in the rumen; therefore, any factor which affects the ability of the rumen microorganisms to digest the starch might affect the utilization of a high grain ration. The rate and amount of starch digestion in the rumen are important in understanding the effect of processing on a cereal grain. Exposure to moist heat increased the rate of in vitro digestion of starch by rumen microorganisms (Salsbury, Hoefer and Luecke, 1961; Osman et al., 1970). Steam or pressure cooking of milo and barley increased the rate of in vitro starch digestion of both grains (Osman et al., 1970). Flaking of steamed or pressure cooked milo and barley further increased the rate of in vitro digestion of starch. The rate of digestion of

starch also increased as degree of flaking increased. In vitro gas production was greater for steam flaked milo and barley (Trei, Hale and Theurer, 1970) than for the untreated grains. Steaming or pelleting of milo and corn increased in vitro gas production compared to cracked grains (Hastings and Miller, 1961). Flaking cooked milo increased gas production, starch digestion and VFA production (Trei et al., 1970) susceptibility to enzymatic attack (Liang et al., 1970) and percent of damaged starch granules of milo (Anstaett and Pfost, 1969). Dry roasting corn (Felsman et al., 1972) at temperatures above 127°C resulted in increased in vitro dry matter disappearance and glucose release. The dry heat processing of cereal grains such as micronizing (Hinders and Eng, 1970; Hinders, 1971) and popping (Walker, Rockwell and Kohler, 1970) resulted in increased in vitro gas production. Dry matter digestibility was also increased when moisture was added to milo before popping. Increasing the moisture level prior to popping increased the percent of the grain which was popped and also the in vitro dry matter digestion (Walker, Rockwell and Kohler, 1970).

In Vivo Starch Digestion

Starch digestion in the ruminant occurs both in the rumen and in the small intestine. Several studies have shown that the type of grain and method of processing effects the site of starch digestion. Concentrate rations composed of barley or flaked corn (Macrae and Armstrong, 1969; Orskov, Fraser and Kay, 1969; Nicholson and Sutton, 1969; Armstrong and Beever, 1969; Orskov, Fraser and McDonald, 1971), have less starch escaping rumen

fermentation than rations of ground corn. Starch passing into the small intestine of sheep and cattle was determined to be about 6 to 11% and 12 to 32% for the barley or flaked corn and the ground corn, respectively. Increasing dry matter intake increased the amount of starch entering the small intestine, but did not decrease overall digestibility of the starch. This is in contrast to observations of Little, Mitchell and Reitnour (1968) and McNeill, Potter and Riggs (1971) where there seemed to be a limit to the amount of starch that could be digested in the small intestine. Almost all ingested starch was digested in a ration of 85% barley fed to sheep (Topps, Kay and Goodall, 1969; Wright et al., 1966) and to steers (Topps et al., 1969; Nicholson and Sutton, 1969). Waldo, Keys and Gordon (1971) found that about 99% of the starch in rations of varying corn content was digested in the total digestive tract. As much as 35% of the starch from a corn ration fed to sheep (Tucker, Mitchell and Little, 1968) passed into the lower tract and was digested there. As estimated by blood glucose levels, heated starch was digested faster in the intestines than nonheated starches (Huber et al., 1961; McAtee, Little and Mitchell, 1966). As the amount of starch in the diet increased the amount of starch entering the abomasum also increased (Karr, Little and Mitchell, 1966).

Less starch escaped rumen fermentation when milo was steamed under 3.5kg/cm pressure than at atmospheric pressure (Holmes et al., 1970). More starch passed to the abomasum in steers fed an 85% milo ration using dry ground or micronized milo than in rations using steam flaked or reconstituted ground milo (McNeill, 1971). Sheep fed whole or rolled barley had 6.0% of the α-linked glucose polymers

entering the small intestine (Macrae and Armstrong, 1969) while the value was 10.4% for a ration containing flaked corn. Orskov et al. (1969) found more starch escaping rumen fermentation in lambs fed uncooked corn diets than those fed barley or flaked corn. More starch from a ground maize diet escaped rumen fermentation than for a diet of flaked maize fed to sheep (Beever, Coehla Du Silva and Armstrong, 1970).

VFA Changes Associated With Grain Processing

Changes in rumen VFA levels and relative VFA proportions have been shown to be associated with consumption of processed grains. The proportions of acetate declined and propionate increased in the rumen after feeding on a diet of cracked maize (Reid, Hogan and Briggs, 1957). The rumen VFA concentrations were greater in steers fed a 90% wheat ration (Oltjen et al., 1965) than in those fed 90% corn; however, there were no differences in VFA ratios between rations. Judson et al. (1968) showed that increasing the starch content of the ration as crushed corn decreased concentrations of total VFA's in the rumen. Topps et al. (1968) noted an increase in the proportions of propionate for a ration of high concentrate intake over a lower concentrate intake and a hay ration when fed to steers. The addition of soluble carbohydrates to flaked corn rations fed to cows increased the proportion of propionate in the rumen (Sutton, 1969).

The above discussion suggests that there are differences in VFA concentrations, VFA proportions and the amount of starch digestion in the rumen of animals fed high concentrate rations. The cereal

grain fed, amount of grain in the ration and processing method appear to change the pattern of the rumen fermentation.

CHAPTER III

INFLUENCE OF PROCESSING METHODS ON DIGESTION OF MILO STARCH IN HIGH CONCENTRATE BEEF CATTLE RATIONS[1,2]

Summary

High concentrate rations containing milo processed by dry rolling, micronizing, steam flaking and grinding were fed in a 4 x 4 Latin square design to steers fitted with permanent rumen and abomasal cannulas. The digestion of starch in the rumen and in the lower digestive tract were determined. No significant differences in the amount of starch digested in the rumen were found between rations. A significantly reduced intestinal digestion and, therefore, a lower total digestion of starch was observed with dry rolled milo. This suggests that the raw starch from dry rolled milo has a reduced accessibility to enzymatic attack in the small intestine.

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The degree of gelatinization was greatest for the micronized and steam flaked milo with small differences between the dry rolled and ground milo. In vitro dry matter digestibilities in 12 hour fermentations indicated that the micronized and steam flaked milo were digested by rumen microorganisms at a faster rate than the non-heat treated milos. The differences in in vitro dry matter disappearance were less after a 24 hour digestion, suggesting that the extent of digestion of raw starch in the rumen approaches that of cooked starch. Differences in volatile fatty acid concentrations and molar percentages were small. There was a slight trend for the acetate to propionate ratio to be lower when the heat and pressure treated milo rations were fed.

Introduction

The feeding of processed milo in rations to fattening cattle has often reduced feed intake but increased efficiency of utilization of the ration. Since the major source of energy from milo is from starch it appears that the digestibility of the starch portion of high concentrate rations may account for the differences observed in feed efficiency. The amount of starch fermented in the rumen depends upon the cereal grain fed and the method of processing. There is evidence to suggest that when ruminants are fed high starch diets, considerable starch escapes fermentation in the rumen and that the capacity of the lower tract to digest starch may be limited. More starch from uncooked maize escaped fermentation than for steam flaked maize (Orskov, Fraser and Kay, 1969). Less than 10% of the ingested starch from diets high in barley and flaked maize entered

the lower intestinal tract of sheep (Macrae and Armstrong, 1969). In contrast, up to 38% of the starch from ground corn fed to steers passed into the abomasum in experiments by Karr, Little and Mitchell (1969). Little, Mitchell and Reitnour (1968) found increasing amounts of starch infused into the abomasum resulted in increasing amounts of starch reaching the terminal ilium, indicating a limited digestibility of starch in the small intestine. Tucker, Mitchell and Little (1968) found the efficiency of digestion of starch in the lower tract to be highly efficient, while McNeill, Potter and Riggs (1971) demonstrated starch from dry rolled and micronized milo was not completely digested in the total tract. Because of the conflicting results concerning starch digestion by the ruminant, this experiment was conducted to further study the digestion of starch in processed milo and to determine the site and extent of starch digestion when steers were fed high concentrate rations.

Experimental Procedures

Four Angus steers weighing approximately 225 Kg were fitted with permanent rumen and abomasal cannulas and were housed in individual pens with slotted floors. The steers were fed an 84 percent milo ration as shown in table I. Four rations differing only in the method by which the milo was prepared were fed in a 4 x 4 Latin square experiment. The steers were fed at hourly intervals with the use of automatic feeders built for this purpose. This feeding system was used to maintain a constant flow of digesta through the digestive tract and to reduce variations in sampling of abomasal contents and feces in order to obtain more accurate

TABLE I

COMPOSITION OF HIGH MILO RATIONS

Ingredient	% In Ration, D. M. Basis	
Milo	84.0	
Cottonseed hulls	7.0	
Dehydrated alfalfa meal	3.0	
Supplement	6.0	
Soybean meal		3.3
Urea		0.7
Minerals, vitamins and additives		1.55
Wheat middlings		0.2
Chromic oxide		0.25

estimates of starch movements through the tract. The system also reduces the large changes in rumen fermentation observed after animals consume large amounts of feed. Feed intake was found to be similar to that observed under feedlot conditions. Chromic oxide was added to the ration as an external indicator to facilitate calculation of starch digestibility.

Rations containing dry rolled, micronized, steam flaked and ground milo were prepared by the following procedures. Dry rolled milo was prepared by passing whole milo through a set of rollers set to crack all kernels. Micronized milo was prepared by passing milo under infrared heaters and then through rollers under 59.1 Kg pressure. Heating time was adjusted so that the density of the final product was 335 g/liter. Steam flaked milo was produced by holding grain in a steam chamber for 35 minutes at atmospheric pressure and then passing through rollers set to produce a product density of 361 g/liter. Milo ground through a 4.76 mm screen in a hammermill was used for the ground milo ration. The milo for this trial was a commercial source of milo of unknown variety or origin.

Samples of abomasal contents and feces were obtained three times daily on two days for each steer on each ration. Samples were dried at 80°C and ground through a 1 mm screen in a Wiley mill. Starch and chromium determinations were conducted on the abomasal contents and feces. Starch was determined as α-linked glucose polymers by the procedure of Macrae and Armstrong (1968). Chromium was determined by atomic absorption spectrophotometry. Digestibility of starch in the various segments of the digestive tract was calculated using chromium as an external indicator.

Samples of rumen contents were obtained just prior to the hourly feeding on two days for each ration and each animal. The samples were strained through 4 layers of cheesecloth and 0.5 ml saturated mercuric chloride was added per 100 ml rumen fluid to stop bacterial action. VFA analysis of rumen fluid was conducted essentially by the procedure of Erwin, Marco and Emery (1961) with a Bendix, Series 2500 Gas Chromatograph. A glass column of 183 cm length and 2 mm inside diameter, packed with 10% SP 1200 on Chromasorb W, acid washed, 80/100 mesh (Supelco, Inc., Bellefonte, Pa.) and a nitrogen flow rate of 60 cc/min was used. Hydrogen flow at 40 cc/min and air flow of 1.6 cc/min was maintained to a flame ionization detector. Column temperature was maintained at 120°C.

In vitro dry matter disappearance (DMD) of the processed grains was determined using the procedures outlined by Johnson (1969). Ten ml of rumen fluid mixed with 15 ml of artificial saliva were added to 0.4 g of ground grain in a test tube. These tubes were then incubated for either 12 or 24 hours at 39°C. The tubes were then centrifuged and the supernatant discarded. After drying at 104°C for 24 hours the percent DMD was calculated. The degree of gelatinization of the processed grains was determined as mg maltose released after incubation with beta-amylase (Sung, 1969). Particle size of the dry rolled and ground milo was determined by the method reported by Ensor, Olson and Colenbrander (1970). Statistical analyses of the data were conducted according to procedures outlined by Snedecor and Cochran (1967).

Results and Discussion

The physical characteristics of the processed milo (table II) demonstrate the differences in processing methods. A mean geometric diameter of 1023 and 398 microns for the dry rolled and ground milo, respectively, indicate the differences in particle size which resulted from these methods. The large amount of the steam flaked and micronized milo which was retained on the larger screens resulted from the flaked or expanded nature of the final product. Thus, the geometric mean diameter was not a valid comparison for these latter two methods of processing. Density of 335 and 361 g/liter for the micronized and steam flaked milo, respectively, was a better indication of processing.

The degree of gelatinization (table III) indicates the amount of damage occurring to the starch granules during processing. Steam flaking and micronizing resulted in more mg of maltose released from beta-amylase digestion than the dry rolled or ground milo. The micronized milo had more damaged starch granules than the steam flaked milo. This indicated that the internal moisture of the milo kernel gelatinized and expanded the grain and the rolling of the heated grain further disrupted the starch granular structure. The disruption of the starch granule by flaking or rolling after heat treating also has been demonstrated by loss of bifringence (Johnson, Matsushima and Knox, 1968).

In vitro dry matter disappearance (DMD) data (table III) indicated that the grain processing methods influenced digestion by rumen microorganisms. A 12 hour in vitro digestion resulted in significantly greater dry matter loss ($P < .05$) from the heat and pressure treated and the ground milo than from dry rolled milo. Dry

TABLE II

PHYSICAL CHARACTERISTICS OF MILO PROCESSED BY VARIOUS METHODS

Item	Method of processing			
	Dry rolled	Micronized	Steam flaked	Ground
Sieve Diameter (microns)		% Retained on screen		
4000	-	52.6	34.7	-
2000	2.1	35.0	46.0	-
1000	72.0	5.6	9.4	22.5
500	14.7	4.7	5.5	34.0
250	5.6	1.0	1.9	18.0
125	3.3	0.7	1.6	7.3
Pan	2.3	0.4	0.9	18.2
Geometric mean diameter[a] (microns)	1023	-	-	398
Geometric standard deviation[a]	1.48	-	-	1.63
Density (g/liter)	-	335	361	-

[a]Procedure described by Ensor, Olson and Colenbrander, 1970.

TABLE III

IN VITRO DRY MATTER DISAPPEARANCE AND DEGREE OF GELATINIZATION OF PROCESSED MILO

Ration	% In vitro dry matter disappearance[a]		Degree of gelatinization
	12 hour	24 hour	mg maltose/g of grain
Dry rolled	38.39[b]	55.61[b]	11.7
Micronized	51.85[d]	58.97[bc]	84.9
Steam flaked	47.07[cd]	63.52[c]	31.7
Ground	43.54[bc]	63.66[c]	7.5
LSD[e]	6.53	7.11	

[a]Values are means of 8 determinations.

[bcd]Means in a column with different superscripts are significantly different ($P < .05$).

[e]Least significant difference.

matter disappearance from micronized milo was also significantly ($P < .05$) greater than from ground milo at 12 hours. Steam flaked milo had a slightly greater DMD at 12 hours than ground milo, but this difference was not significant ($P > .05$). After 24 hours the DMD values tended to show less differences between processing methods. Dry rolled milo had less DMD than steam flaked and ground milo ($P < .05$), but there were no significant differences between micronized, steam flaked and ground milo. After 24 hours of digestion *in vitro* the DMD for the non-heat and pressure treated milo tended to equal the micronized and steam flaked milo. The 12 hour *in vitro* DMD values apparently reflected rate of digestion while 24 hour values reflected extent of digestion by rumen microorganisms. This agrees with data from Schwimmer (1945) which suggested that the difference in digestion of raw and cooked starch was that of rate of digestion. These results also agree with Trei, Hale and Theurer, (1970) and Osman *et al.* (1970).

The total concentration of volatile fatty acids (table IV) in the rumen fluid from steers fed the ground milo was significantly lower ($P < .05$) than the concentrations in those fed the heat and pressure treated milo. The difference could have been due to a lower intake of ground milo and not necessarily due to processing method. There was a tendency for the micronized and steam flaked milo rations to produce a lower pH, higher total volatile fatty acid concentrations and a lower acetate to propionate ratio than the dry rolled and ground milo rations, however, these differences are not significant ($P > .05$).

Ruminal, intestinal and total digestion of starch are shown

TABLE IV

RUMEN PH, TOTAL AND MOLAR PERCENTAGES OF VOLATILE FATTY ACIDS IN STEERS FED PROCESSED MILO

Ration	pH	Volatile fatty acids[a]					
		Total concentration m moles/liter	Molar %				
			Acetic	Propionic	Butyric	Isovaleric	Valeric
Dry rolled	5.5	141.29[bc]	51.39	32.30	10.32	3.86	2.10
Micronized	5.4	155.18[b]	43.71	36.45	14.39	2.60	2.83
Steam flaked	5.4	146.59[b]	47.64	39.43	9.27	2.170	1.47
Ground	5.6	124.22[c]	50.91	33.33	11.48	2.24	2.01
LSD[d]	0.29	19.71	9.81	12.38	5.62	2.88	1.50

[a]Values are means of 16 observations.

[bc]Means in a column with different superscripts are significantly different ($P < .05$).

[d]Least significant difference.

in table V. Feed intakes were similar for the dry rolled, micronized and steam flaked milo rations. The ground milo ration was not as acceptable to the steers, presumably because of the fineness of grinding. Starch intakes reflected feed intakes as starch contents of the rations were similar. The percent ruminal digestion of starch was not significantly ($P > .05$) different between processing methods. Intestinal and total starch digestion were significantly ($P < .05$) lower for the dry rolled milo than for the micronized, steam flaked and ground milo. Total digestion of starch was about 99% for all rations except the dry rolled milo which agrees with Holmes, Drennon and Garrett (1970), McNeill, Potter and Riggs (1971) and Macrae and Armstrong (1969). These authors found that almost all the starch from high cereal grain rations was digested in the total digestive tract.

The total digestion of starch from the dry rolled milo ration was lower than from the other rations. McNeill, Potter and Riggs (1971) also found that dry processed milo had a lower starch digestibility. In contrast to the results of these authors, however, the micronized and steam flaked milo in our experiment did not differ in their starch digestibility. The lowered intestinal digestion of starch from the dry rolled milo ration indicates that the intestinal tract may have a limit as to its ability to digest raw starch as was suggested by Little, Mitchell and Reitnour (1968). Whether this inability to digest all the starch entering the small intestine is of a physical or chemical nature is not clear. Wright, Grainger and Marco (1966) found that the small intestine possessed adequate capacity to hydrolyze soluble starch.

TABLE V

RUMINAL, INTESTINAL AND TOTAL DIGESTION OF STARCH FROM PROCESSED MILO

Item	Grain processing methods			
	Dry Rolled	Micronized	Steam flaked	Ground
Feed intake, g D.M./day	5698	5187	5659	4260
Starch intake, g/day	3722	3382	3737	2687
Ruminal digestion of starch, g/day	2847	2848	3038	2319
Intestinal digestion of starch, g/day	592	520	661	336
Starch in feces, g/day	283	14	38	32
Total digestion of starch, g/day	3439	3368	3699	2655
Ruminal digestion, % of total starch intake	76.5	84.2	81.3	86.3
Intestinal digestion, % of starch entering intestine	67.6[a]	97.2[b]	95.4[b]	89.5[b]
Total digestion, % of total starch intake	92.4[a]	99.6[b]	99.0[b]	98.8[b]

[ab]Values on the same line with different superscripts are significantly different ($P < .05$).

Huber et al. (1961) noted that heated starch introduced into the abomasum was digested faster than raw starch. Therefore, the reduced intestinal digestion of starch from the dry rolled milo ration may be due to the inaccessibility of pancreatic enzymes to the starch molecules, thus reducing overall starch digestion. Starch in the ground milo is considered as raw starch, therefore, it might also be expected that starch digestibility from the ground milo ration would have a lower intestinal digestion than the heat treated milo. However, because of the lower feed intake there was less starch entering the small intestine of steers fed the ground milo. Since particle size of the starch was much smaller for the ground milo than for the dry rolled milo, the data suggest that particle size may influence digestion of starch in the intestines. Trei, Hale and Theurer (1970) also stated that in vitro DMD, gas production and starch digestion were increased by cooking and flaking milo. Osman et al. (1970) suggested that the mechanical action of flaking was important to increase digestion by rumen microorganisms.

The importance of the lower digestive tract for digesting starch becomes important when ruminants are fed high cereal grain diets. Karr, Little and Mitchell (1966) found that as starch intake increased, the amount of starch entering the small intestine increased. The amount of starch entering the small intestines from the rations fed in this experiment (10%) support their findings that significant amounts of starch are presented to the lower digestive tract. The extent to which this starch is digested would influence the efficiency of the animal to convert feed energy into body weight gain. In this experiment about 250 g more starch per day was digested

from the micronized and steam flaked milo rations than for the dry rolled milo ration. Using a caloric value of carbohydrates of 4.15 Kcal/g, this would represent about 1 Mega-calorie additional energy available daily from these rations. Blaxter (1962) states that digestible energy is about 86% metabolizable and that metabolizable energy is used with about 58% efficiency for body gain. Therefore, the additional starch digested would represent about 0.5 Megacalories of energy available for gain which is equivalent to 0.13 Kg body gain per day for steers of this weight. An increase in daily gain of this magnitude for steers fed heat and pressure treated milo has been observed in feeding trials in this country. This suggests that the increased starch digestion for heat and pressure treated milo noted in this experiment would explain much of the increased feed efficiency and/or increase in daily gain observed in feeding trials.

CHAPTER IV

INFLUENCE OF DEGREE OF MICRONIZATION ON THE SITE AND EXTENT OF MILO STARCH DIGESTION IN HIGH CONCENTRATE BEEF CATTLE RATIONS[1,2]

Summary

High concentrate rations containing milo processed by dry rolling or micronizing were fed in a 4 x 4 Latin square design trial to steers fitted with permanent rumen and abomasal cannulas. Degree of micronization of the milo was varied to produce products with densities of 412, 322 and 232 g per liter. Automatic feeding devices designed to feed 24 times daily were used to create steady state conditions in the digestive tract. The digestion of milo starch in the rumen and lower digestive tract was determined. No significant differences in the amount of starch digested in the rumen were found between rations. A significant reduced intestinal

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digestion and therefore a lower total digestion of starch was observed with dry rolled milo, suggesting that raw starch from dry rolled milo has a reduced accessibility to enzymatic attack in the small intestine. Ruminal digestions of starch from the three micronized milo rations were not significantly different; however, differences tended to favor the higher degree of micronization. Degree of micronization also had little influence on intestinal and total digestion of starch.

The degree of gelatinization of milo starch increased as the degree of micronization increased. The 12 hour in vitro dry matter disappearance indicates that micronized grain was digested at a faster rate and that this rate increased as degree of micronization and degree of gelatinization increased. The differences in in vitro dry matter disappearance after 24 hours were smaller but still favored the micronized milo. A narrower ratio of acetate to propionate and a greater total concentration of volatile fatty acids was observed in rumen fluid from steers fed micronized milo than in those fed dry rolled milo.

Introduction

Recent evidence suggests that the efficiency of utilization of cereal grains may be improved by dry heat processing to a degree comparable to other processing techniques. Feeding trials with milo fed to steers (Garrett, 1968; Schake et al., 1970; and Riggs et al., 1970) and corn fed to lambs (Cunningham and Perry, 1972) indicate that feed efficiency was increased when grain was dry heat processed. Walker et al. (1970) found no differences between steam

flaked and popped milo and barley in digestibility of dry matter, organic matter and crude protein. Schake et al. (1970) noted no differences in animal performance of steers fed steam flaked or micronized milo.

In vitro enzymatic digestion of popped milo increased as degree of popping increased (Walker et al., 1970). In vitro microbial digestion of processed grain proceeded at a faster rate for steam flaked and micronized milo than for dry rolled or ground milo (Hinman and Johnson, 1973). McNeill, Potter and Riggs (1971) found that less starch from micronized milo was digested in the rumen and total digestive tract than starch from steam flaked and reconstituted milo. In contrast, ruminal and total digestion of starch was found to be similar for steam flaked and micronized milo (Hinman and Johnson, 1973). The results from feeding trials would indicate that starch digestion would be similar for these processing methods.

This experiment was conducted to further study starch digestion from micronized milo and to determine the influence of degree of micronization on in vivo starch digestion and in vitro dry matter digestion.

Experimental Procedures

Four Angus steers weighing approximately 250 Kg were fitted with permanent rumen and abomasal cannulas and were housed in individual pens with slotted floors. The steers were fed an 84 percent milo ration as shown in table VI. Four rations differing only in the degree of micronizing were fed in a 4 x 4 Latin square

TABLE VI

COMPOSITION OF HIGH CONCENTRATE RATIONS

Ingredient	% In Ration, D.M. Basis
Milo	84.0
Cottonseed hulls	7.0
Dehydrated alfalfa meal	3.0
Supplement	6.0
Soybean meal	3.3
Urea	0.7
Minerals, vitamins and additives	1.55
Wheat middlings	0.2
Chromic oxide	0.25

experiment with a seven day adjustment period for each ration prior to sampling. The steers were fed at hourly intervals with the use of automatic feeders built for this purpose. This feeding system was used to maintain a constant flow of digesta through the digestive tract and to reduce variations in sampling of abomasal contents and feces in order to obtain more accurate estimates of starch digestion. The system also reduces the large changes in rumen fermentation observed after animals consume large amounts of feed. Feed intake was found to be similar to that observed under feedlot conditions. Chromic oxide was added to the ration as an external indicator to facilitate calculation of starch digestibility.

Rations containing dry rolled and micronized milo were prepared by the following procedures. Dry rolled milo was prepared by passing whole milo through a set of rollers to crack the kernels. Micronized milo of three densities 412, 322 and 232 g/liter, was prepared by varying the time of exposure and/or intensity of heat from infrared heaters in the micronizer[4]. The heated milo was then passed through a set of rollers under 59.1 Kg pressure. The milo for this trial was purchased from a commercial source and was of unknown origin or variety.

Samples of abomasal contents and feces (rectal grab samples) were obtained three times daily on two days for each steer on each ration. Samples were dried at 60°C and ground through a 1 mm screen in a wiley mill. The three samples of abomasal contents or feces

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[4]Micronizer courtesy of Chardo Pierce Micronizing Company, Amarillo, Texas.

taken within one day were then composited and the composite sample subjected to starch and chromium determinations. Starch was determined as α-linked glucose polymer by the procedure of Macrae and Armstrong (1968). Chromium was determined by atomic absorption spectrophotometry. Digestibility of starch in the various segments of the digestive tract was calculated using the chromium as an external indicator.

Samples of rumen contents were obtained just prior to the hourly feeding on two days for each ration and each animal. The samples were strained through 4 layers of cheesecloth and 0.5 ml of saturated mercuric chloride was added per 100 ml to stop bacterial action. VFA analysis of rumen fluid was conducted essentially by the procedure of Erwin, Marco and Emery (1961) with a Bendix Series 2500 Gas Chromatograph. A glass column of 183 cm length and 2 mm inside diameter, packed with 10% SP 1200 on Chromosorb W, acid washed, 80/100 mesh (Supelco, Inc., Bellefonte, Pa.) and a nitrogen flow rate of 60 cc/min were used. Hydrogen flow at 40 cc/min and air flow of 1.6 cc/min was maintained to a flame ionization detector. Column temperature was maintained at 120°C.

In vitro dry matter disappearance (DMD) of the processed grains was determined using the methods suggested by Johnson (1969). Ten ml of rumen fluid mixed with 15 ml of artificial saliva was added to 0.4 g of ground grain in a tared test tube and incubated for either 12 or 24 hours at 39°C. The tubes were centrifuged and the supernate discarded. After drying at 104 C for 24 hours and weighing, the percent DMD was calculated. The degree of gelatinization of the processed grains was determined as mg maltose released after

incubation with beta-amylase (Sung, 1969). Particle size of the dry rolled milo was determined by the method reported by Ensor, Olson and Colenbrander (1970). Statistical analyses of the data were conducted according to procedures outlined by Snedecor and Cochran (1967).

Results and Discussion

The physical characteristics of the processed milo are shown in table VII. A mean geometric diameter of 1003 was obtained for the dry rolled milo. Considerable amounts of the micronized milo were retained on the larger sieves resulting from the popped or expanded nature of the grain from this process. As the degree of micronization increased a larger percentage of the micronized milo was expanded and, therefore, more retained on the larger sieves. Thus, the geometric mean diameter was not a valid comparison for the micronized milo. Densities of 412, 322 and 232 g/liter for the low, medium and high degrees of micronization, respectively, were a better indication of processing.

The degree of gelatinization (table VIII) indicates the amount of damage occurring to the starch granules during processing. Micronized milo resulted in greater enzymatic digestion by beta-amylase than did the dry rolled milo and as degree of micronization increased the mg of maltose released increased. This indicates that the internal moisture of the grain kernel was being vaporized by the dry heat and was gelatinizing the starch molecules as well as expanding the milo kernel. Walker et al. (1970) also found that the expansion of dry heat processed milo was related to the rate of

TABLE VII

PHYSICAL CHARACTERISTICS OF PROCESSED GRAIN

Item	Method of processing			
		Micronized		
	Dry rolled	Low	Medium	High
Sieve diameter (microns)	% Retained on screen			
4000	-	30.9	60.0	65.0
2000	6.0	47.1	29.1	21.2
1000	64.3	15.4	4.6	5.9
500	17.7	3.7	3.2	4.4
250	5.1	1.4	1.7	2.0
125	3.9	1.1	0.9	1.0
Pan	3.0	0.4	0.5	0.5
Geometric mean diameter[a] (microns)	1003	-	-	-
Geometric standard deviation[a]	1.94	-	-	-
Density (g/liter)	-	412	322	232

[a]Procedure described by Ensor, Olson and Colenbrander, 1970.

TABLE VIII

IN VITRO DRY MATTER DISAPPEARANCE AND DEGREE OF GELATINIZATION OF PROCESSED MILO

Ration	% In vitro dry matter disappearance[a]		Degree of gelatinization
	12 hour	24 hour	mg maltose/g of grain
Dry rolled	41.08[b]	61.67[b]	9.3
Micronized (low)	51.88[c]	65.30[bc]	37.1
Micronized (med.)	53.30[c]	65.48[bc]	79.3
Micronized (high)	55.75[c]	68.99[c]	112.5
LSD[d]	5.56	4.48	

[a]Values are means of 8 determinations.

[bc]Means in a column with different superscripts are significantly different ($P \leq .05$).

[d]Least significant difference.

in vitro enzymatic digestion. Reeve and Walker (1969) observed that a greater amount of the starch in well popped or expanded milo was gelatinized than in poorly popped milo. Presumably, the flaking or rolling of the heated grain further increased the disruption of the starch granule as was demonstrated by loss of bifringence (Johnson, Matsushima and Knox, 1968) and by *in vitro* enzymatic digestion (Osman *et al.*, 1970).

In vitro dry matter disappearance (DMD) data (table VIII) indicated that the grain processing methods influenced digestion by rumen microorganisms. Micronized milo had a significantly greater ($P < .05$) dry matter loss than the dry rolled milo after a 12 hour *in vitro* digestion. There were no significant ($P > .05$) differences in the 12 hour *in vitro* digestion for the three degrees of micronization, although increasing degree of micronizing tended to increase the 12 hour digestion. The 24 hour *in vitro* digestion for the dry rolled milo was lower than for the micronized milo but this difference was significant ($P < .05$) only for the high degree of micronizing. There were no significant ($P > .05$) differences in 24 hour digestion between the three micronized milos. Thus, micronization appeared to increase the rate of digestion of milo starch (12 hour) but had a lesser effect on the extent (24 hour) of digestion. This agrees with data from Schwimmer (1945) and Salsbury, Hoefer and Luecke (1961) which suggested that the difference in digestion of raw and cooked starch was that of rate of digestion. These results also agree with data from Trei, Hale and Theurer, (1970), Osman *et al.* (1970) and Hinman and Johnson (1973).

The total concentration of volatile fatty acids (VFA) (table IX)

TABLE IX

RUMEN PH, TOTAL CONCENTRATIONS AND MOLAR PERCENTAGES OF VFA'S FROM STEERS FED PROCESSED MILO

Ration	pH	Volatile fatty acids[a]					
		Total concentration m moles/liter	Molar %				
			Acetic	Propionic	Butyric	Isovaleric	Valeric
Dry rolled	5.6	109.48[b]	63.23[b]	20.72[b]	10.82	3.80[b]	1.41
Micronized (low)	5.5	127.85[bc]	50.04[c]	37.69[c]	8.95	1.44[c]	1.86
Micronized (med.)	5.4	151.72[c]	43.88[c]	42.97[c]	10.14	1.09[c]	1.89
Micronized (high)	5.4	150.25[c]	47.65[c]	39.53[c]	9.13	1.38[c]	2.28
LSD[d]	.22	28.24	8.01	9.09	4.34	1.29	1.03

[a]Values are means of 16 observations.

[bc]Means in a column with different superscripts are significantly different ($P < .05$).

[d]Least significant difference.

in the rumen fluid from steers fed the dry rolled milo was significantly lower ($P < .05$) than the concentrations in those fed the medium and high degree of micronized milo. There were no significant differences ($P > .05$) between concentrations in the rumen fluid of steers fed the three degrees of micronized milo. Rumen fluid from steers consuming dry rolled milo had a significantly ($P \leq .05$) lower molar percentage of propionic acid and had higher molar percentages of acetic and isovaleric acids than rumen fluid from steers consuming micronized milo. Thus, a lower acetate to propionate ratio was observed in rumen fluid from the steers fed micronized milo. There was a tendency for the rumen fluid from the steers fed micronized milo to have a lower pH than rumen fluid from steers fed dry rolled milo, suggesting more of the ration was being fermented in the rumen or that fermentation was proceeding at a faster rate.

Ruminal, intestinal and total digestion of starch are shown in table X. Feed intakes were quite similar for the four rations, although slightly less of the dry rolled milo was consumed daily. Starch intakes reflected feed intakes. The percent ruminal digestion of starch was not significantly different ($P > .05$) between processing methods; however, the trend was for greater ruminal digestion as the degree of processing increased. Both intestinal and total digestion of starch from the dry rolled milo ration were significantly ($P < .05$) lower than comparable measurements for the three micronized milo rations. About 98% of the starch from the micronized milo rations was digested in the total digestive tract. These values agree with other data on starch digestion of processed

TABLE X

RUMINAL, INTESTINAL AND TOTAL DIGESTION OF STARCH FROM PROCESSED MILO

Item	Grain processing methods			
	Dry rolled	Micronized		
		Low	Medium	High
Feed intake, g D.M./day	5516	5976	6156	6012
Starch intake g/day	3494	3778	3914	3746
Ruminal digestion of starch g/day	2100	2297	2509	2544
Intestinal digestion of starch g/day	744	1405	1338	1120
Starch in feces, g/day	650	76	67	82
Total digestion of starch g/day	2844	3702	3847	3664
Ruminal digestion, % of total starch intake	60.1	60.8	64.1	67.9
Intestinal digestion, % of starch entering intestine	50.9[a]	95.4[b]	95.5[b]	92.9[b]
Total digestion, % of total starch intake	81.4[a]	98.0[b]	98.3[b]	97.8[b]

[ab]Values on the same line with different superscripts are significantly different ($P < .05$).

milo (Macrae and Armstrong, 1969; McNeill et al., 1971; Karr, Little and Mitchell, 1966 and Hinman and Johnson, 1973).

Only about 81% of the starch from the dry rolled milo ration was digested in the total tract. This decreased starch digestion is primarily a reflection of the decreased intestinal digestion of this ration. Particle size determination of the dry rolled milo indicated that about 4% of the milo kernels were not cracked or broken and therefore might pass through the digestive tract undigested. Four percent of the starch would be about 140 g of starch passing through the digestive tract in a form not available for digestion. However, the undigested starch passing through the digestive tract from this ration amounted to 650 g. Thus, the small amount of starch from the whole kernels (140 g) does not completely explain the lowered digestion of starch observed from the dry rolled milo. It appears that some of the raw starch is not digested in the intestinal tract either by enzymatic hydrolysis in the small intestine or bacterial fermentation in the cecum and large intestine. Huber et al. (1961) and Wright, Grainger and Marco (1966) also noted that intestinal digestion of soluble or cooked starches was greater than raw starch when measured by blood glucose response.

Greater than 90% of the starch entering the intestines from the micronized milo was digested in the intestinal tract suggesting that the levels of starch entering the intestines in this experiment did not exceed the capacity of the steer to digest cooked starch in the lower digestive tract. Karr et al. (1966) and McNeill et al. (1971) suggest that there may be a limit as to the amount of starch that can

be digested in the intestines. The data from this experiment and that of Hinman and Johnson (1973) suggest that there may be a limit to the digestion of raw starch in the intestines; however, the amount of cooked starch digested in the intestines in this experiment indicate that the limit for digestion of cooked starch may be greater than that for raw starch.

Approximately 400 g more starch from the dry rolled milo ration escaped both ruminal and intestinal digestion than from the micronized milo rations which represents a considerable loss of energy which is not available for body gain. Using a caloric value of carbohydrates of 4.15 Kcal/g this would represent about 1.66 Megacalories additional energy for gain available daily from the micronized milo. Digestible energy is about 86% metabolizable and metabolizable energy is used with about 58% efficiency for body gain (Blaxter, 1962). Therefore, the additional starch digested would represent about 0.8 Megacalories of energy available for gain which is equivalent to 0.20 Kg body gain per day. This suggests that the increased starch digestion for the micronized milo would explain much of the increase in feed efficiency observed in feeding trials with dry heat processed cereal grains.

CHAPTER V

AN AUTOMATED FEEDING SYSTEM FOR REDUCING THE VARIATIONS IN DIGESTIBILITY MEASUREMENTS

The customary method of feeding experimental rations (two or three times daily) results in large changes in rumen fermentation patterns. Increasing the frequency of feeding decreased the range of values for pH and VFA concentrations in the rumen of sheep fed a roughage diet (Faichney, 1968 and Hungate, 1966). Volatile fatty acid concentrations increased and pH decreased rapidly after feeding when sheep were fed twice daily. Small changes in VFA concentrations and pH occurred when sheep were fed at three hour intervals (Faichney, 1968).

Because of the nature of the ruminant to digest large amounts of the feed dry matter in the rumen, the flow of ingesta to the lower tract is less variable than the changes in rumen parameters. Knight, Owens and Garrigus (1972) noted that at two to three hours postfeeding there was an increase in dry matter flow to the abomasum then a steadily declining dry matter flow until after the next feeding. Hogan and Phillipson (1960) noted that the flow of digesta into the duodenum was not greatly variable, however, a slight increase was observed six hours postfeeding. Most digestibility studies use the total collection of feces to calculate digestion coefficients for feedstuffs. Since total collection of

abomasal contents is not practical and collection of total feces requires a metabolism stall or special equipment, it was necessary to modify the feeding techniques to allow more accurate use of analytical data from "grab" samples. An automatic feeder designed to feed at hourly intervals was used in these experiments to create "steady state kinetics" or continuous flow within the digestive tract.

Automatic feeders (Eriez Mfg. Co., Erie, Pa.) equipped with a timing device and variable intensity magnetic vibrators were used to feed experimental animals at hourly intervals. Experimental design and procedures are described in Chapter III. Digestibility of starch from a high concentrate ration was calculated using each of the three samples of abomasal contents and feces collected on each of two days for each animal on each ration in the experiment described in Chapter II. Analysis of variance of the data (table XI) indicated that there were no significant variations ($P > .05$) in digestibility of starch between samples within a day or between days. There were no significant interactions ($P > .05$) between days, samples, rations, periods or animals. This would indicate that a relatively constant fermentation in the rumen followed by a constant flow of digesta into the lower tract was occurring when these animals were fed hourly.

Hourly feeding reduces the variation in rumen pH and VFA concentrations and allows for a more constant flow of digesta out of the rumen and along the lower digestive tract. This would suggest that fewer samples of ingesta would need to be obtained from this feeding system than from the conventional twice a day feeding system because of a reduced diurnal variation in flow of digesta

TABLE XI

ANALYSIS OF VARIANCE OF RUMINAL AND TOTAL STARCH DIGESTION DATA

Source	d.f.	Ruminal digestion M.S.	Ruminal digestion F	Total digestion M.S.	Total digestion F
Period	3	902.55	1.74	52.26	1.28
Animal	3	615.71	1.19	57.60	1.41
Ration	3	863.09	1.66	551.74	13.55[a]
Error A	6	518.89		40.71	
Day	1	13.19	0.08	49.67	2.89
Period x day	3	16.56	0.10	30.22	1.76
Animal x day	3	195.31	1.16	22.96	1.33
Ration x day	3	10.71	0.06	38.45	2.24
Error B	6	168.12		17.16	
Sample	2	57.13	0.57	46.34	1.43
Period x sample	6	67.14	0.67	41.92	1.29
Animal x sample	6	104.24	1.04	40.76	1.26
Ration x sample	6	52.27	0.52	21.29	0.66
Error C	12	99.47		32.27	
Day x sample	2	32.74	0.37	31.24	1.49
Period x day x sample	2	22.95	0.25	31.31	1.50
Animal x day x sample	2	44.04	0.49	21.33	1.02
Ration x day x sample	2	20.63	0.23	18.29	0.87
Error D	12	88.70		20.89	
Duplicate (Period, animal, ration, day, sample)	96	1.17	0.01	23.57	0.86
Residual	36	174.45		27.36	

[a]Significant ($P < .05$).

through the digestive tract.

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VITA

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