CEREAL GRAINS IN FEEDLOT RATIONS: INFLUENCE OF TYPE AND METHOD OF PROCESSING UPON STARCH AND PROTEIN DIGESTIBILITY

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PREFACE

Scientifically, this research may have raised as many questions as it sought to answer. While the observations and facts reported herein are based on objective measures, there were additional observations, classified as "subjective", which were not able to be quantified.

It is these subjective observations which have intrigued me. In the eight months of feeding these steers, I noticed specific taste preferences for various grains and processing methods. Steam flaked corn appeared to be the "elite" of cereal grains as evidenced by appetite and time taken to eat. Consumption of coarser, scratchier grains (oats and barley) was slower. With high moisture ensiled corn, there was definitely an increase in the amount of time needed to consume all of the feed, and physical activity of the steers was noticeably decreased. While sampling from the rumens during the in situ trial, it was interesting to note differences in the particle size of the grains, the degree of ruminal raft, and the homogeneity of the ruminal contents. Rolled wheat diets created the greatest ruminal raft; whereas, steam flaked grains had the least raft development. Homogeneity of the ruminal contents tended to increase as particle size of the grain decreased and as time increased post-prandially.

About midway of the trials, the steers developed shipping fever, causing the trials to be suspended one month. The steers in the site and extent of digestion trial had never received any kind of pre-conditioning, unlike the steers in the in situ trial which received a complete vaccination program. Recovery time for the preconditioned cattle was definitely shorter than for the other group. Some research reports indicate limited or no benefit from preconditioning. This could be due to the method of measuring the response. Differences between the two kinds of receiving programs might be more pronounced if subacute cases of shipping fever complex could be identified and might help to explain "poor-doers" in the feedlot.

About five weeks into the in situ trial, one steer developed a thiamin deficiency. This deficiency is thought to be a rare condition, sometimes associated with high-concentrate diets. Soon after this steer's bout with thiamin deficiency, a midwestern feedlot had 27 head succumb to the same deficiency. There is a need to investigate the nutritional, genetic, and management factors which might predispose feedlot animals to thiamin deficiency.

This kind of endeavor would not have been possible had there not been the support from a great many people. I would like to thank Jerry Peterson of Circle E Feedlot, Inc., Potwin, KS for his cooperation in processing the steam flaked milo; Dr. Bob Lake of Hitch Feeders I, Inc., Hooker, OK for his help in processing the steam flaked corn

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Owens, my advisor, supported me not only financially but professionally in directing the scope of this research. Dr. D. R. Gill helped me in the selection and procurement of the cereal grains. Dr. J. R. Kropp helped facilitate the purchase and transportation of the steers. Dr. E. C. Nelson advised me on the laboratory analyses. Dr. D. L. Weeks spent numerous hours assisting me in the merging and statistical analyses of the data.

Last, but not least, my appreciation and thank you goes to my family and my fiance, Kent Newby. My father, now deceased, instilled in me the love for the land and agriculture. My mother and brother, Gene, have helped me maintain this perspective and have supported me faithfully through the rough and good times. Kent Newby has encouraged me to explore new horizons and has helped me to maintain a daily sense of humor.

Finally I owe a big recognition to the following steers:

FRITZ
YANKEE
SNIP
APOLLO
CASPER
SCOOTER
COTTON
BLACKY

I developed a deep respect and love for these steers. It was their trial, and this thesis is dedicated to them.

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CHAPTER I

INTRODUCTION

Cereal grains are the major ingredient in feedlot diets, providing most of the starch and a considerable portion of the protein. Corn, wheat, milo, barley and oats are the grains most commonly included in midwestern feedlot rations. Selection of the type of cereal grain for the ration depends upon availability, cost and facilities for processing the grain. Grains usually are processed to improve feed efficiency.

Certain processing methods not only increase total tract digestibility, but also alter the site (ruminal vs intestinal) of digestion and absorption of various nutrients such as protein and starch (Hibberd, 1982). The need for processing varies with type of cereal grain. Processing may be minimal, such as with whole shelled corn, or may be very extensive, as with steam flaked milo.

Several researchers have published reviews of the factors affecting site and extent of starch digestion in ruminants (Waldo, 1973; Rooney and Pflugfelder, 1986; Orskov, 1986; Owens et al., 1986; and Theurer, 1986). There is a considerable amount of research concerning digestion of starch in corn and milo, but data on barley, wheat and oats

is less available. Information regarding protein degradation of cereal grains in the rumen is even more scarce. For oilseed meals, 26 in vivo estimates of bypass have been published. In contrast, for all the cereal grains combined, only 13 values are available (NRC, 1985). These values are quite variable, and many have been determined in sheep. Differences between species in terms of particle retention in the reticulo-rumen and fineness of chewing make extrapolations of data from sheep to cattle inadvisable (Stern and Satter, 1982).

Most bypass estimates consider only total non-ammonia nitrogen. Eventually, escape values for individual amino acids within each protein source will be needed. When the precise amino acid requirements have been established, it should be possible to manipulate the amino acid flow at the duodenum specifically to meet the amino acid requirements. Ways useful to accomplish this include feeding protected protein, protected amino acids, or protein sources relatively stable against breakdown in the rumen, and adjusting the dietary nutrient balance to achieve a particular post-duodenal supply (Buttery, 1981).

Preferential hydrolysis of some amino acids from the peptide or protein molecule by microbes has been suggested (Chalupa, 1976). More extensive degradation of basic amino acids was noted by Stern and Satter (1982), although Weakley (1983) noted that soybean meal escaping microbial degradation in the rumen had an amino acid composition quite

similar to that of soybean meal fed to steers. With feedstuffs containing diverse protein types, as with prolamines and glutelins present in cereal grains, the potential for discriminatory loss of specific amino acids is greater. Detailed information on the amino acid profiles of cereal grains escaping ruminal digestion and reaching the small intestine is needed.

The objectives of this research were as follows:

1. To determine the differences in starch digestion and ruminal protein bypass among five cereal grains.
2. To examine the effect of grain processing method upon starch and protein degradation of the cereal grain in the rumen and small intestine.
3. To investigate the amino acid profile of bypassed protein.
4. To determine the relationships among pH, rate of passage and ruminal disappearance of starch and protein in cereal grains.

CHAPTER II

REVIEW OF LITERATURE

This review of the literature is not a comprehensive summation of all the data published concerning the factors affecting the digestion of starch and protein in cereal grains. Instead, this review focuses upon the literature published after 1973 and upon the factors considered most important. The review will deal with factors affecting starch and protein digestion in cattle only. Gill (1980) proposed that grain processing affected factors, such as particle size, site of digestion, amount of soluble and bypass protein, rate of availability of carbohydrates and nitrogen for ruminal fermentation, and feed intake. These factors, plus pH and type of grain are discussed below.

Type of Grain and Method of Processing

The major source of energy in formulated feeds for livestock is cereal grain. Grains are processed to improve feed efficiency, feed handling, and acceptability to animals and to livestock owners. Economic considerations govern not only the extent to which cereals are used in ruminant feeding, but also the extent to which processing of cereals can be justified. While economics of cereal

processing and feeding very markedly with time, nutritional aspects apply at any time (Hutton and Armstrong, 1975).

The extent to which protein is degraded in the rumen depends upon microbial proteolytic activity in the rumen, microbial access to the protein, and rumen turnover. Microbial access to the protein often is the factor limiting protein degradation in the rumen. Protein from small grains, such as barley and oats, is more extensively degraded in the rumen than is the protein from corn (NRC, 1985).

Processing can increase the efficiency of utilization of dietary constituents, improve the palatability of high cereal diets, and consequently improve animal performance. However, processing is not always essential; unprocessed grains may be nutritionally equal, or even superior, to processed grains (Hutton and Armstrong, 1975). Whole shelled corn can be utilized satisfactorily when roughage levels are low; it possesses inherent roughage characteristics. Consequently, whole shelled corn can serve to reduce the incidence of liver abscesses, to reduce acidosis and to increase feed intake and average daily gains. When grain processing costs are high, it may be advantageous to use whole shelled rather than processed corn in many feedlot rations (Cole et al, 1976b).

Grain is processed by two basic methods: "hot processes" in which heat is either applied or created during the treatment process and "cold processes". These

two categories can be further subdivided into wet or dry processes. Wet processes add water to the cereal or harvest and store the grain at a high moisture content. Examples of these processes (Hale, 1973) are listed below:

Dry Processing	Wet Processing
Whole grain	Soaking
Grinding	Steam rolling
Dry rolling or cracking	Steam processing and flaking
Popping	Reconstitution
Extruding	Exploding
Micronizing	Pressure cooking
Roasting	Early harvesting
Pelleting	Ear corn silage
Thermalizing	Sorghum head silage

Processing of cereal grains can alter both the physical form and the chemical composition of the grains. Processing improves the utilization more for sorghum grain and corn than for barley and wheat. Utilization of milo can be improved 15% by proper steam processing and flaking (Hale, 1973). Corn also is improved by steam processing and flaking. Galyean (1977) with in situ studies noted than more dry matter and starch were digested from steam flaked corn within each particle size and time than for dry, ground corn. Steam processing and flaking improved digestibility of barley only if the digestibility of the barley was low (Parrott et al., 1969).

Generally, corn has more starch (68 vs 60%), but less protein (10 vs 13%) than milo (Wagner, 1978). The distribution of the protein among different wet-milling fractions differs between sorghum and corn. Starch granules are embedded or surrounded by a protein network,

described as a proteinaceous matrix. This matrix may reduce the feeding value by restricting the accessibility or availability of the starch to digestion in the rumen and/or intestine. The bran and germ portion represents the seed coat and embryo of the grain or kernel, while the gluten and peripheral endosperm cell fractions include this protein matrix. The peripheral endosperm cell fraction is 3 to 4 times greater in sorghum grain than corn. This suggests a much tighter encapsulation of starch within the kernel so more effort must be expended to obtain full utilization of starch. This is one of the reasons that sorghum is improved more than is corn by processing.

Processing methods such as steam flaking and reconstitution raise sorghum digestibility to near that of corn. Processing methods affect the disruption of the protein matrix and simplify access of bacterial or animal enzymes to the starch granules (Hale, 1973). Starch granules undergo gelatinization, or irreversible loss of native structure, when sufficient energy is applied to break intermolecular hydrogen bonds in crystalline areas. During gelatinization, the starch granules absorb water, swell, exude part of the amylose, become more susceptible to enzyme degradation and lose birefringence. Digestibility of the starch generally is inversely proportional to amylose content (Rooney and Pflugfelder, 1986).

Heat processing also may induce other changes in the chemical composition of the dry matter of cereals. In some cases reduced oil levels have been noted. This may be due to de-germing of cereals under some conditions of processing because the major oil-containing components of cereal grains is the germ. With corn, the fines remaining beneath the rollers after flaking may contain up to 20% oil and 14% crude protein. Therefore, physical removal of grain components rich in specific nutrients is of major significance in any consideration of processing and product composition (Hutton and Armstrong, 1975).

Certain feed processing methods (pelleting, extrusion, steam rolling and flaking) generate enough heat to alter feed protein (NRC, 1985). Thus, the form and amount of protein required for optimal growth may change drastically when the physical and chemical form of the feed is changed by processing (Prigge et al., 1978). Heating can disrupt the crystalline structure of cereal starches and greatly increase rates of hydrolysis and fermentation (Baldwin and Allison, 1983). Whether heating renders protein less susceptible to ruminal attack depends on the degree of heat and the type of protein. Depressed nitrogen and oil content in heat processed cereals may result from de-germing of the cereal grains, and/or loss of ammonia from non-protein nitrogenous constituents such as glutamine, asparagine, or amides in the grain. The extent of de-germing is dependent on the physical conditions associated

with the rolling or flaking processes; nitrogen loss depends upon the temperature of processing (Hutton and Armstrong, 1975). Although all protein reaching the small intestine is assumed to have a digestibility of 68% (NRC, 1985), comparable digestibility for zein and casein would be surprising based on digestion studies with non-ruminant animals. This can be confirmed by Little and Mitchell (1967) who abomasally infused lambs with four different proteins (purified soybean, zein, gelatin, and casein) to compare intestinal digestibilities and utilization. Protein digestibilities were 73.50, 54.86, 79.08, and 78.52%, respectively.

Anti-nutritional factors, such as enzyme inhibitors, phytates, lectins, and tannins also may affect starch utilization. Tannins present in brown, bird resistant sorghums will bind protein and inhibit some enzymes (Rooney and Pflugfelder, 1986).

In the past, attention has focused primarily on the starch portion of cereal grains because starch constitutes 70 to 80% of the grain by weight and cereals provide a major energy source in animal feeds. Waldo (1973) reported average starch concentrations of 71.9, 70.2, 63.8, 44.7 and 64.6 for corn, sorghum, wheat, oats, and barley, respectively. The effect of processing on the utilization of cereal proteins, lipids, vitamins and minerals has received little attention (Hutton and Armstrong, 1975).

With high moisture corn, most of the vitamin E present is lost during storage (Young et al., 1984). Thiamin deficiencies have been noted among cattle fed high grain diets, yet supplementation of high-concentrate diets with thiamin has yielded inconsistent results (Grigat and Mathison, 1982). Could this be due to the type of grain fed and the method of processing?

Particle Size

Adequate flaking following heat treatment of cereal grains is needed to achieve an appreciable degree of gelatinization (Hutton and Armstrong, 1975). During steam flaking, water and heat move into the kernel, causing swelling of starch. Rolling of the hot, moist grain disrupts some of the swollen granules, forming a paste that binds the remaining material into a strong flake. The surface area and enzyme susceptibility of the starch are greatly increased (Rooney and Pflugfelder, 1986). Increases in flake flatness improve starch digestion. Poor flakes are no better than the untreated grain (Hale, 1975).

For feeding to cattle, barley should be coarse ground or rolled prior to feeding. Comparisons between cold and heat processed barley have given contradictory results, but small improvements with heat processed barley generally are not associated with increased digestibility. Wheat grain also does not respond to heat processing. The slightly adverse effect of steam flaking on wheat digestibility has

been attributed to the extremely fragile nature of the flakes and the high percentage of fines produced (Hutton and Armstrong, 1975). Hinman and Johnson (1974) noted that starch digestion was greater for ground sorghum grain than for dry rolled sorghum grain and attributed this effect to differences in particle size.

Feeding larger particle sizes of corn to sheep does not decrease total tract digestibility in sheep, but feeding larger sizes to cattle has reduced digestibility consistently (Waldo, 1973). Species differences (sheep and goats versus cattle) appears to be associated with the size of the reticulo-omasal orifice. For larger animals the size of the orifice does not prevent whole grain from entering the abomasum. If grains are not cracked during eating, there is a low likelihood that it will be digested because access to bacteria and digestive enzymes requires fracture of the seedcoat (Orskov, 1981). However, some degree of alteration of the whole kernel beyond mastication damage is necessary to maximize ruminal and total tract digestibility, as whole corn generally is lower in these measurements than are ground diets (Galyean, 1977).

Rate of digestion of starch from grain in the rumen varies inversely with particle size of the grain (Galyean et al., 1981). With processed grains, amylolytic bacteria attach immediately. Colonization of starch is very rapid with steam flaked or gelatinized starch. The proportion of

microbes which are attached to particles has been constant with diets ranging from 25 to 75% concentrate (Owens, 1985).

Corn digestibilities by cattle are maximum when the geometric mean diameter is between .83 and 2.9 mm (Waldo, 1973). In one trial, digestible energy values increased as particle size of whole corn was reduced to .64 cm. Kim and Owens (1985) reported that processing to a particle size larger than 250 um but smaller than 1000 um may be ideal for abetting flow of digestible starch to the small intestine. Galyean (1977) indicated that for dry corn grain particle size is more important than time of ruminal incubation for dry matter and starch digestion. Dry matter digestion approximately doubled as particle size was reduced by half from 3000 to 1500 to 750 microns. But for steam flaked corn, time of incubation appeared to be more important than particle size for digestion rate of starch and dry matter in the rumen. Conversely, particle size appeared to have a greater impact than time on ruminal digestion rate of high moisture corn. Increased time for fermentation could not overcome effects of particle size on dry matter digestion of unprocessed corn. Particle size also had significant effects on digestion of dry matter from sorghum grain.

Although particle size reduction of grain increases the extent of starch digestion in the total tract, especially in the rumen, smaller particles also expose more

surface area to microbial attack in the rumen and in the large intestine and to enzymatic attack in the small intestine. The physical size of particles containing starch also can limit digestion of starch in the intestine (Hinman and Johnson, 1974, Owens et al., 1986). Particles reaching the small intestine from whole corn often are large and are not extensively attacked in the small intestine. Teeter et al. (1980) found that 67 to 75% of the total starch in the feces of steers fed whole corn was present in whole corn particles. Passage rate of particles from the rumen also can be influenced by particle size (Poppi, 1980), though for large particles, increased fermentation time has limited benefit.

Rate of Availability of Carbohydrates and Nitrogen for Ruminal Fermentation

Processing of grains to increase starch digestion in the entire tract of the ruminant animal invariably increases the amount and proportion of starch digestion occurring in the rumen. From 42 to 98% of the starch digested by ruminants occurs in the rumen (Waldo, 1973). Processing improves the efficiency of grain utilization by increasing the total amount of starch digested by the rumen micro-organisms and/or the animal (Hale, 1973).

The amount of starch fermented in the rumen depends upon the cereal grain fed and the method of processing (Hinman and Johnson, 1974). Waldo (1973) concluded ruminal digestion of barley starch was 94%. In contrast, corn starch digestibility was only 74%. More corn than barley starch escaped ruminal digestion. Sorghum starch digestibility was 42%, lower than any values for ground corn. Quantitative data on ruminal digestion of wheat or oat starch by cattle is limited. Axe et al. (1987) reported ruminal starch digestibilities of wheat were 93.5%.

Ruminal digestion of barley starch is not affected by cereal processing method. In contrast, processing of corn may affect particle size, and thereby, ruminal digestion. Compared with processing methods that reduce particle size, ensiling generally increases ruminal more than intestinal digestion of starch (Owens et al., 1986). Gill (1980) ranked (in descending order(ruminal digestion of processed corn types as 1) steam flaked, 2) ground high moisture, 3) acid treated high moisture, 4) dry rolled, and 5) whole shelled corn. Flaking increased ruminal digestion of corn starch equivalent to that of barley starch. Moist heat treating of sorghum starch increased ruminal digestion to equal that of barley (Waldo, 1973).

To maximize efficiency of animal production and reduce the need for intact protein in the diet, microbial digestion in the rumen is useful. Output of microbial

yield from the rumen generally increases as the amount of organic matter fermented in the rumen increases (Owens, 1985). Hence, carbohydrate and protein digestion in the rumen are interdependent. Bacterial cells represent a sizable energy and protein by-product of ruminal fermentation even on natural protein feeds. As nonprotein nitrogen use increases, the importance of bacterial protein as a source of essential amino acids increases. Waldo (1973) reported that the quantity of bacterial protein synthesized per 100g OM digested ranges from 8.2 to 23 g. Processing of corn or sorghum starch to increase ruminal digestion should increase the contribution of microbial nitrogen. Reconstituting and steam flaking sorghum also increased ruminal breakdown of feed protein.

In contrast to total yield, microbial efficiency is independent of yield. Efficiency usually is greater with less extensive digestion in the rumen and lower total yield. Hence, microbial efficiency usually is greater with whole than processed grain diets despite lower total yield (Owens, 1985). Cole et al. (1976a) noted microbial efficiency was greater with dry rolled than steam flaked corn.

Site of Digestion in the Gastrointestinal Tract

The effects of heat processing of cereals on the site of digestion may be even more important than processing

effects on overall digestibility of the cereal (Hutton and Armstrong, 1975). Site of digestion of starch and protein is shifted downstream by increased feed intake, decreased grain processing or less buffering of the ration (Owens et al., 1980). For 51 observations, Waldo (1973) reported that total tract starch digestibilities for barley, corn, and sorghum averaged 99%. Total utilization efficiency should be reduced as ruminal starch digestion increases due to the heat and methane losses with microbial fermentation. Concentrate rations that introduce starch in the small intestine for enzymic digestion should be more efficient than those extensively fermented in the rumen provided that little starch fermentation occurs in the large intestine. Performance data from growing cattle fed processed corn and sorghum grains indicate that starch is used more efficiently if it is digested in the small intestine rather than in the rumen (Owens et al., 1986). Processing also probably enhances energy and N economy for the animal by minimizing starch fermentation and microbial protein synthesis in the lower gut (Theurer, 1986).

Starch fermentation in the rumen has as energetic efficiency of 75 to 80%. Corn starch escaping fermentation may contribute up to 8.6 g glucose/kg$^{\cdot 75}$ to the ruminant. The bovine small intestine can digest up to 7.7 g corn starch/kg$^{\cdot 75}$/day. Up to 14.2 g sorghum starch/kg$^{\cdot 75}$/day has entered the small and large intestine with total tract digestibility at 97% (Waldo, 1973). Processing of corn or

sorghum decreases intestinal starch digestion 33% or more compared with post-ruminal starch digestion of nonprocessed corn or sorghum grain (Theurer, 1986).

Orskov (1986) reported the capacity for raw digestion of corn starch in the small intestine of sheep is limited to 100 to 200 g/day; gelled starch could be digested in quantities up to 200 to 300 g/day. Owens et al. (1986) reported between 18 and 42% of the total dietary starch from corn and sorghum grains fed to cattle reaches the small intestine. In the small intestine, from 47 to 88% of the presented starch is digested, while in the large intestine, 33 to 62% of the presented starch is digested. Despite decreasing supply to the intestine, processing tended to increase digestibility of starch reaching the intestines.

Orskov (1986) suggested that the capacity for post-ruminal digestion of starch is limited by lack of enzymes for hydrolysis of short chain di- and oligosaccharides and also by capacity for absorption of glucose. Though limits to digestion in and absorption from the small intestine can be demonstrated by infusing starch and glucose into the duodenum, Owens et al. (1986) stated that enzymatic capacity does not appear to limit intestinal starch digestion because no plateau in the amount of starch disappearing from the small intestine can be detected with typical diets. Yet, extent of digestion is incomplete.

Digestibility of unfermented dietary protein in the small intestine varies considerably, especially if the protein has been processed to reduce its availability in the rumen. If intestinal digestibility is low, then fermentation in the caecum and colon can lead to a wasteful loss of nitrogen as ammonia. The digestibility of total nitrogen in the small intestine varies from about 60 to 70%. This is a composite value for the microbial cells including the cell walls, the resistant plant materials and the digestible escape feed protein (Thomas and Rook, 1981).

Amount of Soluble Protein and Protein Bypass

Protein flow to the small intestine of the ruminant is the sum of the dietary protein which escapes ruminal degradation and the microbial protein (bacterial and protozoal protein) synthesized in the rumen (Stern and Satter, 1982). Ruminal bacteria and protozoa alone provide insufficient amounts of protein for high producing ruminants. Hence, increased ruminal bypass (escape) protein may increase production of high producing ruminants (NRC, 1985). The solubility of dietary protein influences both the extent to which it escapes degradation in the rumen and thereby, the flow and composition of protein entering the small intestine. Only the protein degraded in the rumen provides nitrogen for microbial protein synthesis (Thomas and Rook, 1981).

Proteins of low solubility generally are utilized more efficiently than proteins of high solubility; more dietary protein reaches the intestine intact and less cycles through the process of degradation to ammonia and resynthesis into microbial protein (Prigge et al., 1978). Conversely, for effective rumen fermentation of dietary carbohydrates, an adequate supply of ammonia nitrogen must be present to promote microbial growth and activity. If a sizeable fraction of the nitrogen in feeds cannot be degraded (or converted) to ammonia nitrogen, extent of digestion in the rumen can be depressed with an concomitant depression in animal performance (Bergen, 1976). However, if the dietary protein is of poor quality (amino acid composition), utilization may be improved through ruminal degradation and conversion into microbial protein (Prigge et al., 1978).

Heat processed cereals generally have nitrogen with very low solubility but a high rate of starch fermentation in the rumen. Thus, more amino acids may be available for absorption in the duodenum of ruminants fed processed than unprocessed cereals, particularly when non protein nitrogen is supplemented. Availability of amino acids, or more precisely specific amino acids, in the duodenum often is the first limiting factor for ruminant animal production (Hutton and Armstrong, 1975).

High moisture processing methods result in similar improvements in animal performance as do heat/moisture processed grains; however, very little of the starch in high moisture grains is gelatinized. Solubilization of the protein matrix surrounding starch granules is extensive during high moisture storage. This increases accessibility of starch granules to rumen microorganisms. Additionally, water penetration may cause embryonic development which causes the aleurone layer to secrete amylases to liquify the starch. In either case, increased protein solubility generally accompanies improvement in the availability of the starch (Smith, 1976).

With high moisture feeds, 35 to 75% of the protein is in a water soluble form (Gill, 1980). Solubilization of nitrogen varies with moisture content of the grain in ensiling (Galyean, 1984). At higher moisture contents, soluble protein, percentage starch, and starch availability of the fermented grain all increase (Aguirre, 1984). If ammonia is being released in the rumen from high moisture corn, as would be expected from the high solubility of nitrogen and it does not accumulate in the rumen, either ammonia use by rumen bacteria must be enhanced or ammonia absorption must be accelerated. Usually ammonia is used more extensively for microbial protein synthesis with high moisture grain rations (Prigge, 1976).

The requirement for supplemental rumen bypass protein may be greater in the case of feeding high moisture corn than dry grain. Reduced rates of passage from the rumen and rumen turnover may depress microbial efficiency (output of microbial protein per unit of organic matter digested in the rumen) which could depress the amino acid supply of the animal. Conversely, ensiled feeds may be exposed to elevated temperatures for a sustained period of time during fermentation. This would render protein more resistant to ruminal fermentation. Heat damaged protein may or may not be available for post-ruminal digestion (Merchen and Satter, 1983).

The two forms of processing which promote the greatest amount of ruminal fermentation (steam flaking and high moisture harvest) will likely be the two forms which promote the greatest degree of protein destruction in the rumen. Steam flaked and high moisture corn also should enhance conversion of ruminal ammonia to microbial protein. Cole et al. (1976a) found more nitrogen tended to be lost from the rumen with steam flaked than with dry rolled corn. They suggested that the process of gelatinization exposed more of the corn protein for microbial attachment. Microbial protein synthesis per unit of dry matter fermented and bypass of dietary protein were greater with whole shelled and dry rolled corn than with steam flaked

corn. Compared with processed grain, whole shelled corn feeding should assist in bypassing a larger amount of both the grain and protein supplement (Gill, 1980).

In contrast, factors which increase starch digestion (processing and grain sources) may reduce feed protein escape while increasing the amount of microbial nitrogen presented to the intestines (Theurer, 1986). Some exceptions are apparent. Galyean et al. (1976) reported that less of the total corn nitrogen (8 vs 12%) was soluble in steam flaked than dry rolled corn. Several processing treatments (heat, tannin, formaldehyde, etc.) have been used to decrease the proportion of dietary protein which is degraded in the rumen. The most favorable processing conditions have been shown to produce a net increase in the flow of amino acids to the small intestine and in their absorption, although responses differ between specific amino acids (Thomas and Rook, 1981).

Rate of Passage

Large differences between the performance of animals fed the same diet now are known to be ascribed primarily to differences in ruminal outflow rate and partially to differences in fermentation rate of starch (Orskov, 1986). Greater ruminal fermentation of dry matter and starch from high moisture grains versus other processing methods may be due to a lower rate of passage from the rumen. Lower rate

of passage also may be associated with depressed microbial efficiencies and could depress the amino acid supply to the animal (Smith, 1976).

Turnover rate of rumen contents is an important factor in the increased efficiency of microbial protein synthesis. Increased efficiency of energy utilization is associated with a dilution of the maintenance expenditure of bacteria, decreased storage of carbohydrates by bacteria and or a reduction in protozoal numbers and predation on bacteria (Prigge et al., 1978).

Chemical and physical factors which alter rumen turnover, such as rate of digestion, rumen fill, rate of passage, particle size and saliva flow should have a profound impact on microbial protein synthesis (Prigge et al., 1978). Complex interrelationships exist between these chemical and physical factors. For example, ruminal liquid outflow parameters, though not significantly influenced by corn particle size, tend to increase with increasing particle size (Galyean, 1977). Sharp et al. (1982) observed liquid turnover rates were 29% greater ($P<.10$) with steers fed corn in the whole rather than the ground form; this might be attributed to greater salivary input.

With high concentrate diets, the dilution rate is generally low (Thomas and Rook, 1981). Cole et al. (1976a) indicated that at low dilution rates, ruminal microbial protein synthesis is highly dependent upon the rumen dilution rate. However, microbial efficiency is not always

directly related to fluid passage; occasionally the relationship has been inverse. Instead, particulate passage rate often is found to be more closely related to microbial efficiency than fluid passage rate (Owens, 1985). Accelerating the rate of passage of processed grain, by addition of certain roughages such as cottonseed hulls, should shift the site of digestion of both starch and protein to the intestine and may improve energetic efficiency (Kim and Owens, 1985).

Consistency of duodenal and ileal digesta varies drastically with diet composition. High viscosity could limit the exposure of particles or solutes to the intestinal wall, and theoretically could reduce starch digestion in the small intestine. Watery digesta dilute enzymes and reduces their concentration. Digesta flow at the ileum appears to increase with fiber content of digesta, so time for intestinal digestion of starch may be altered by fiber source and digestibility (Owens et al., 1986).

pH

Low ruminal pH often occurs when starchy grain is included in diets for ruminants. This drop in pH depresses fiber digestion. Some of this problem can be overcome by reducing extent of cereal processing and other methods that prevent low ruminal pH (Orskov, 1986).

Conversely, extensive grain processing may reduce the time during which fiber digestion is depressed and permit compensatory digestion of fiber to resume either later in a feeding cycle or later in the digestive tract. With unprocessed grains, the degree of inhibition of fiber digestion immediately after the meal is less, but the pH is depressed for a more prolonged time as the grain is masticated and becomes available later in the feeding cycle (Owens, 1985). Thus, with meal-fed animals, grain processing can alter extent of fiber digestion. With nibbling animals consuming meals frequently, this interaction would not occur.

Barrio (1984) suggested that the extent of proteolysis in the rumen is modified by diets which alter ruminal pH primarily because pH influences protein solubility. With most protein supplements, protein solubility decreases as pH decreases, but with protein from corn grain, solubility instead <u>increases</u> as pH decreases (Isaacs and Owens, 1972).

Feeding ground grain diets results in some problems, namely inadequate saliva secretion to maintain ruminal pH between 6 and 7 and inadequate physical structure in the feed to stimulate ruminal motility. Animals fed processed diets spend less time eating and ruminating, both activities which stimulate salivary secretion. Because VFA production is high due to rapid fermentation, ruminal pH often is low so animals can suffer from ruminal acidosis and parakeratosis. Ruminitis and parakeratosis result in

clumping and necrosis of ruminal papillae. Cattle hairs may become embedded in the epithelium, resulting in bacterial invasion into the portal system. Consequently, liver abscesses frequently occur. Lack of fibrous structure in finely ground diets leads to lack of tactile stimuli, inadequate abrasion of ruminal epithelium and reduced ruminal motility (Orskov, 1986).

The method of processing can alter ruminal pH. With high moisture corn, rumen pH usually is lower than with other processing methods, probably because of an increase in the readily fermentable energy (Prigge, 1976). Because whole grain has less surface area exposed, it is fermented more slowly than processed grain. Animals spend more time chewing and ruminating, both of which increase saliva production and ruminal buffering of pH. This tends to decrease ruminal propionate production and ruminitis (Orskov, 1986). Galyean et al. (1976) noted that VFA concentrations tended to be inversely related to ruminal pH.

In cattle, particularly larger cattle fed whole grain diets, up to 30% of the whole grain can appear in the feces. Thus, external processing is required to maximize efficiency (Orskov, 1986). The challenge is to select a processing method which produces grain with a slow rate of ruminal fermentation but remains easily digested post-ruminally.

Intestinal pH depends on diet composition. Cattle fed non-buffered all-concentrate diets have intestinal pH values which are considerably lower than the 6.9 necessary for optimal activity of pancreatic alpha amylase (Wheeler and Noller, 1977).

With processed grains, fiber digestion in the cecum plus large intestine can compensate for some of the depression in the rumen; such renewed fermentation is not as extensive with less well processed diets. Compensatory digestion in the large intestine with rolled or whole grain diets usually is depressed, probably due to renewed starch fermentation in the large intestine which reduces pH and inhibits digestion of cell wall materials (Aguirre, 1984). Thus, grain processing can alter the composition of digestion in the intestines (Owens et al., 1986).

Low fecal pH generally is associated with large amounts of starch in feces of cattle fed high concentrate rations. In two cattle trials, the correlation coefficients relating fecal pH to starch in feces were -.82 and -.94 (Wheeler and Noller, 1977). Turgeon, Jr. et al. (1983) also noted a negative relationship (r=-.42) between fecal starch and fecal pH. Thus, a relationship between a suboptimal pH in the small intestine and decreased utilization of dietary starch is indicated. A low fecal pH reflects incomplete starch digestion, but whether this is due to animal effects or poor grain processing can not be easily determined. Altering pH of the small intestine by

adding dietary buffers appears physiologically impossible (Owens et al., 1986). In contrast, Gill (1980) indicated fecal pH shows nothing. He noted that the dryer the feces, the higher the starch content. If this trend holds, then feces which worry cattle feeders the most may reflect the highest starch utilization.

Conclusions

Complex interrelationships exist between the type of grain/method of processing and the factors affecting starch and protein digestion in feedlot cattle. Further research is needed to ascertain the quantitative importance of these parameters and to determine the responses achieved at variable levels of feed intake and with variable proportions of the cereal grain in the diet. Only then will it be possible to formulate least cost but highly efficient rations for feedlot cattle.

CHAPTER III

EFFECT OF CEREAL GRAIN TYPE AND METHOD OF PROCESSING UPON THE SITE AND EXTENT OF DIGESTION IN FEEDLOT STEERS

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Summary

Five grains (wheat, oats, corn, barley, and milo), processed by five methods [rolling, high moisture ensiling (25% and 35% moisture), steam flaking, and steam rolling] were fed to steers in three 5 x 5 latin square design experiments to investigate the effect of cereal grain type and method of processing upon the site and extent of digestion. Grains with larger particle sizes (whole shelled corn and rolled corn) tended to produce lower ruminal pH values than smaller grains processed similarly. Type of grain did not affect rumen volumes or passage rates of fluid or Yb-labeled grain particles. Rolled corn, wheat, and barley had greater total tract and ruminal organic matter digestion than rolled milo or oats. Rolled milo had less ruminal and total starch digestion than rolled corn, barley, wheat, or oats. Wheat had less ruminal escape

protein and produced greater ruminal ammonia concentrations than corn and milo. Total tract N digestion was positively related with total tract starch digestion ($r=.49$; $P<.0001$). More extensive grain processing (steam flaking versus rolling) tended to produce lower ruminal pH, lower ruminal ammonia, and higher fecal pH values. Ruminal fluid passage rates were greatest ($P<.04$) with 25% high moisture ensiled corn, but grain particle passage rates and rumen volumes were not altered by grain processing methods. As extent of processing increased, total organic matter and starch digestion tended to increase primarily due to increased ruminal digestion. For protein, total tract digestion tended to increase but ruminal digestion was decreased by more extensive processing.

(Key Words: Grain Processing, Grain Type, Protein Digestion, Starch Digestion, Steers)

Introduction

Cereal grains, the major source of energy and protein in feedlot diets, usually are processed to improve feed efficiency (Hutton and Armstrong, 1975). Certain processing methods not only increase total tract digestibility, but also can alter the site (ruminal vs intestinal) of digestion and absorption of various nutrients such as protein and starch (Hibberd, 1982). While the effects of processing upon starch digestion from sorghum, corn, and barley have been investigated extensively, less data is available

for oats and wheat. Little data exists concerning effects of the type of grain or method of processing upon the rate of ruminal exit of the cereal grains.

Protein flow to the small intestine of the ruminant is the sum of the dietary protein which escapes ruminal degradation and the microbial protein (bacterial and protozoal protein) synthesized in the rumen (NRC, 1984). More quantitative information on the extent of protein degradation from cereal grains in the rumen is needed. For barley grain, only two escape values (.14, .28) have been determined, both with sheep; for corn three values (.48, .64, .73) are available; for sorghum grain (milo) eight values (.20 to .69) have been published (NRC, 1985). Differences between species in terms of particle retention in the reticulo-rumen and fineness of chewing make extrapolation of data from sheep to cattle inadvisable (Stern and Satter, 1982). Further information concerning the effects of grain source, grain processing and ruminal conditions on ruminal escape and small intestine digestion of protein from cereal grains is needed to properly formulate and process diets for growing and finishing cattle.

The objectives of the research were 1) to determine the differences in extent of starch digestion and ruminal protein bypass among five cereal grains; 2) to examine the effects of grain processing methods upon starch and protein degradation of the cereal grain in the rumen and the small intestine; and 3) to determine the relationship between

rate of passage and ruminal disappearance of starch and protein in cereal grains.

Materials and Methods

Five steers (282 kg) each fitted with a ruminal cannula and t-cannulas in the duodenum proximal to the bile duct and in the ileum were used in three 5 x 5 latin square designs. Diets (Tables 1 and 1A) consisted of cereal grain (77%), cottonseed hulls (12%), molasses (2%), and a pelleted supplement (8.5%). Urea was added to diets to avoid deficiencies of ruminal ammonia and maintain maximum microbial activity. Chromic oxide (.30%) was added as an indigestible marker. Treatments in the first latin square included rolled corn (RC), whole shelled corn (WSC), steam flaked corn (SFC), rolled wheat (RW), and steam flaked wheat (SFW). The second latin square examined differences among high moisture corn at 25% and 35% moisture levels (C25 and C35), rolled corn (RC), steam flaked milo (SFM), and rolled milo (RM). The final latin square tested differences among rolled barley (RB), steam rolled barley (SRB), rolled corn (RC), rolled oats (RO), and whole oats (WO). Steers were fed twice daily at 0630 and 1830 h so that daily dry matter intake was equal to 1.5% of each steer's initial weight.

Grains were processed commercially from a single batch of grain. Whole shelled corn was number two, yellow dent corn grown in 1985. Part of this corn was dry rolled and

Table 1. Composition of Finishing Diets

Ingredient	% of Dry Matter	
Grain[a]	77.22	
Cottonseed hulls (IFN 1-01-599)	12.00	
Cane molasses (IFN 4-04-696)	2.00	
Chromic oxide[b]	.30	
Pelleted supplement	8.48	
Calcium carbonate (IFN 6-01-069)		1.29
Dicalcium phosphate (IFN 6-01-080)		.24
Vitamin A-30[c]		.01
Potassium chloride (IFN 6-03-755)		.61
Trace mineral salt		.50
Sodium sulfate (Na_2SO_4) (IFN 6-04-292)		.50
Urea (IFN 5-05-070)		1.00
Rumensin 60[d]		.02
Tylan 40[e]		.04
Dry rolled corn (IFN 4-02-931)		4.27
Analysis[f]		

[f]Grains fed were dry rolled and whole shelled corn (IFN 4-02-931); steam flaked corn (IFN 4-28-244); 25% and 35% high moisture corn (IFN 4-20-770); rolled and steam flaked wheat (IFN 4-05-268); rolled milo (IFN 4-20-894); steam flaked milo (IFN 4-16-295); rolled and whole oats (IFN 4-03-309); and rolled and steam rolled barley (IFN 4-00-549).

[b]All diets contained chromic oxide as an indigestible marker.

[c]Vitamin A-30 = 30,000 USP/g.

[d]Rumensin 60 = 60 g/lb.

[e]Tylan 40 = 40 g/lb.

[f]Analysis for each diet is presented in Table 1A.

Table 1A. Analysis of Finishing Diets

Item	Diets												
	RC	WSC	SFC	25C	35C	RW	SFW	RM	SFM	RO	WO	RB	SRB
Crude protein, %	11.28	11.05	10.41	11.41	11.62	15.01	14.71	11.92	11.92	12.94	12.38	14.26	13.96
Starch, %	68.09	69.41	69.60	56.23	58.65	64.74	58.97	65.21	64.01	41.55	37.72	59.65	59.46
Acid detergent fiber, %	10.80	10.36	9.70	11.40	11.94	10.05	9.50	11.10	10.65	22.85	22.16	12.13	13.49
Ash, %	4.73	4.69	4.70	4.62	4.76	5.17	5.08	4.78	5.00	6.23	6.51	5.53	5.57
Chromic oxide, %	.29	.24	.31	.29	.29	.29	.30	.29	.29	.28	.28	.29	.28

part was steam flaked. Steam was applied at 210°F at atmospheric pressure for one hour. The roller was set to achieve a bulk density of 26.1 pounds per bushel. Dry matter content was taken on the rolled corn, and the amount of water to be added to the grain to achieve a final moisture content of 25% or 35% was calculated. This amount of water then was added to the grain in a horizontal mixer and allowed to mix with the rolled corn for 20 minutes. The moistened corn was double bagged in plastic, excess air was evacuated by vacuum pump, and the bags were double secured. The corn was allowed to ensile at room temperature (70°F) for nine weeks prior to feeding.

Whole red winter wheat was grown in 1986 and was number one quality. Part of this wheat was dry rolled so as to barely crack the kernel; part of the whole wheat was steam flaked. Water was added at the elevator at 3% (raised the moisture from 10 to 13%) for four hours. Steam was applied at 210°F at atmospheric pressure for one hour. The roller was set to achieve a bulk density of 27.4 pounds per bushel.

Whole milo was grown in 1986 and was number two quality. Part of the milo was dry rolled so as to barely crack the kernel; part of the milo was steam flaked. Super Kemflake Liquid (contains propionic acid, deionized water, ammonium chloride, trisodium phosphate, monoglyceride, diglyceride, acetic acid, propylene glycol, and artificial color; produced by Kemin Industries, Des Moines, Iowa) was

applied via a surge bin above the steamer at a rate of .013% of the total finished ration (.3 pound per ton of milo) for 45 minutes. Water also was applied in the surge bin above the steamer at a rate of 3.6% for 45 minutes. Steam was applied for 45 minutes at 210°F at atmospheric pressure. The roller setting yielded flakes with a bulk density of 20 pounds per bushel.

Number two barley, grown in 1986, was purchased as whole and steam rolled barley. The whole barley was dry rolled to just barely crack the kernel. Steam rolled barley was steamed at 125°F for 20 to 25 minutes. Whole oats were grown in 1986 and were dry rolled in a roller mill to just crack the hulls.

To characterize the grains, random samples were dry sieved through a series of screen sizes (8mm, 4mm, 2mm, 1mm, 500 microns, 250 microns and 125 microns) to determine their particle size distribution (Table 2). Bulk densities (g/100 cc) of the feeds were 43.51 (SFC), 66.70 (RC), 76.65 (WSC), 56.10 (25C), 64.62 (35C), 62.35 (RW), 54.87 (SFW), 70.77 (RM), 53.03 (SFM), 44.00 (RO), 49.48 (WO), 47.47 (RB), and 53.72 (SRB).

Periods lasted 14 days with sampling from the rumen, duodenum, ileum and rectum on days 10 through 13. At 1830 h of day 8, a rectal sample was obtained prior to feeding 150 g of ytterbium-labeled cereal grain (300 g for the two high moisture corn diets) to estimate passage rate of particles through the rumen. A fluid marker (100 ml of CoEDTA

Table 2. Particle Size Distribution of Processed Grains

Grain and form	Size of sieve openings							
	8mm	4mm	2mm	1mm	500um	250um	125um	Pan
	------ Percentage of grain remaining on screen ------							
Steam flaked corn	28.9	38.5	18.8	7.9	3.6	1.6	.2	.7
Whole shelled corn	25.8	73.4	.8	--	--	--	--	--
Rolled corn	3.2	49.4	40.6	6.0	.4	.2	.2	--
25% High moisture corn	4.6	37.4	39.9	11.3	4.8	1.1	.2	.9
35% High moisture corn	5.0	36.2	42.8	13.0	2.2	.3	--	.6
Rolled wheat	--	6.3	79.0	13.5	.8	.1	.3	.1
Steam flaked wheat	--	31.5	55.0	11.8	.9	.2	.2	.4
Rolled milo	--	--	57.6	41.7	.6	--	.1	.1
Steam flaked milo	--	9.7	43.7	30.0	10.1	4.8	.7	1.1
Rolled barley	--	30.3	67.0	2.6	.1	--	--	--
Steam rolled barley	--	40.8	58.8	.3	--	--	--	--
Rolled oats	--	16.0	77.2	4.6	1.1	.4	.4	.4
Whole oats	--	14.9	82.2	2.7	.1	--	--	--

containing at least 700 mg Co plus 150 ml distilled water) was intraruminally dosed prior to the morning feeding on day 12. Rumen samples were withdrawn via cannula on day 12 before dosing and 2, 15, 27, and 39 h post-dosing. Ruminal pH was measured, the fluid was strained through four layers of cheesecloth, 1 ml of 20% H_2SO_4 was added per 50 ml of strained fluid, and the sample was frozen for later analysis.

Samples from the duodenum (250 ml), ileum (100 ml), and rectum were obtained 38, 44, 50, 56, 65, 70 and 77 h after feeding the ytterbium-labeled grain, and pH was measured immediately. Duodenal, ileal, and a portion of the fecal samples from each animal within each period were composited on an equal wet volume basis and dried for 48 hours in a 60°C oven. The remaining portion of each individual fecal sample was dried individually for Yb analysis. Feed samples were collected on days 9 through 14 and composited within each diet and period. All dry samples except feeds were ground through a Wiley mill fitted with a 2 mm screen and stored at room temperature for future analyses. Feed samples were ground and frozen for future analyses.

Rumen samples were thawed and 45 g were centrifuged twice at 10,000 g for 10 minutes. The supernatant fluid was reserved for analysis of CoEDTA concentration by atomic absorption spectroscopy and for ammonia-N (Broderick and Kang, 1980). Feed, duodenal, and fecal samples were analyzed for dry matter (DM; 90 C for 24 h), ash (600 C for 12

12 h), Kjeldahl nitrogen (N; AOAC, 1975), starch (MacRae and Armstrong, 1968), acid detergent fiber (Georing and Van Soest, 1970), and chromium (Fenton and Fenton, 1979). Individual fecal samples were analyzed for ytterbium concentration (Ellis et al., 1982) to determine particle passage rate. Passage rate was estimated as the slope of the natural logarithm of Yb concentration in dry matter against sampling time. Duodenal samples were analyzed for ammonia-N by distillation over magnesium oxide (AOAC, 1975) and for nucleic acid-N (Zinn and Owens, 1982).

During two of the periods within each latin square, an additional 1500 ml of strained rumen fluid was collected in iced flasks 2 h post-prandially on day 14 for isolation of bacteria. This fluid was strained through 4 layers of cheesecloth, centrifuged twice at 200 g for 5 min to remove feed particles and protozoa, and the supernatant fluid centrifuged at 24,000 g to precipitate bacteria. The pellet was washed twice, once with .9% saline and once with water and recentrifuged at 24,000 g for 15 min after each washing. The pellet then was lyophilized and stored for DM, Kjeldahl-N, and nucleic acid analyses to quantitate daily microbial nitrogen passage to the duodenum. Calculations were based on comparisons of daily duodenal nucleic acid N flow with content of N and nucleic acid in bacterial samples collected in two of the five periods of feeding. Calculations of daily bacterial N flow in the remaining three periods of each square were based on the average of the in-

dividual bacterial values within the feed source. Daily amounts of N flowing past the duodenal cannula were calculated by subtracting the ammonia and microbial contribution from the total. Daily duodenal organic matter (OM) flow, corrected for microbial contributions, was calculated from duodenal organic matter minus duodenal microbial organic matter (microbial OM averaged 9.39%N).

Data for the individual latin squares was analyzed for steer by latin square interactions. Because interactions were not significant for each variable ($P>.05$), the data was pooled across the three latin squares. Treatment means were analyzed using a general linear model program for the pooled data. Classes included latin square, period in latin square, steer, and grain. Treatment means were generated via least squares means procedures, but differences between these means were determined only by selected paired comparisons either within a particular kind of grain to examine the method of processing, or within a particular method of processing to examine the type of grain. Estimated differences, the probability of each difference, and the standard error of these differences were obtained for each paired comparison. Simple correlations among various factors also were calculated by linear regression of the two factors.

Results and Discussion

Mean ruminal pH (Table 3) was affected ($P<.05$) by the method of processing. Flaking reduced ($P<.001$; SE=.07) ruminal pH of steers with both the corn and milo diets by .25 and .28 units. This may be attributed to differences in particle size and surface area available for ruminal fermentation. In contrast, Galyean et al. (1976) and Hinman and Johnson (1974) detected no differences in ruminal pH between rolled and steam flaked corn or rolled and steam flaked milo diets, respectively. Steers fed the smaller particle sized SFC had a lower (.24 and .31) ruminal pH than steers fed corn of larger particle sizes, i.e. WSC and 25C ($P<.004$; SE=.07 and .10, respectively). Steers fed 25C had a higher ruminal pH (.15) than steers fed 35C ($P<.05$; SE=.07). Aguirre (1984) also noted this trend, suggesting that with more moisture in the feed, input of salivary liquid and buffers may decrease which would allow ruminal pH to fall. In this trial, ruminal and fecal pH in all treatments were higher than expected for a 77 percent ration. This may relate to the modest yet limited feed intake which was imposed to reduce the incidence of subacute and acute digestive disturbances.

The type of grain also affected ruminal pH (Table 4). When fed SFW, ruminal pH of the steers was .17 units greater than when steers were fed SFC ($P<.03$; SE=.08) and .24 units greater than when they consumed SFM ($P<.03$; SE=.11).

Table 3. Effect of Method of Processing on Mean Digestive Tract Measurements in Feedlot Steers

Item	Diets												
	RC	WSC	SFC	25C	35C	RW	SFW	RM	SFM	RO	WO	RB	SRB
Ruminal pH	6.64[ab]	6.63[ab]	6.39[c]	6.70[b]	6.55[ac]	6.59	6.56	6.60[b]	6.32[a]	6.69	6.68	6.67	6.65
Duodenal pH	2.70[b]	2.71[ab]	2.71[ab]	2.88[ab]	3.10[a]	2.63	2.74	3.08	2.71	2.94	3.17	2.75	2.86
Ileal pH	7.62	7.63	7.75	7.79	7.66	7.86	7.82	7.75	7.67	8.06	8.13	7.95	8.11
Fecal pH	6.35[a]	6.48[ab]	6.66[b]	6.56[ab]	6.56[ab]	6.68	6.84	5.97[a]	6.55[b]	6.78	6.97	6.68	6.71
Ruminal ammonia-N, mg/dl	8.00[b]	8.33[b]	2.13[a]	10.54[b]	10.29[b]	17.45	14.77	7.99	4.56	9.82	9.97	15.12	13.01
Ruminal fluid,													
passage rate, %/h	3.66[a]	3.83[ab]	4.11[ab]	5.36[b]	3.95[a]	3.93	4.19	3.92	3.30	4.26	3.92	5.29	4.27
volume, liter	70.80	63.80	64.10	51.10	75.20	70.50	79.10	55.90	48.10	82.10	107.50	72.90	73.40
outflow, ml/h	2452.00	2136.00	2421.00	2336.00	2404.00	2655.00	2312.00	1898.00	1592.00	3221.00	4056.00	3235.00	2919.00
Particulate passage rate, %/h	2.38	2.78	2.36	1.78	2.06	2.34	2.66	1.82	1.80	1.65	2.83	1.33	1.40
Flow to duodenum[e]:													
dry matter, g/h	93.10	112.50	96.80	98.30	94.80	100.40	88.30	110.00	101.10	125.30	113.80	91.30	94.20
dry matter, %	4.00[a]	6.12[b]	4.35[ab]	3.86[ab]	3.87[ab]	4.25	4.57	5.32	5.64	4.27	3.21	3.11	3.48
Flow to duodenum[e]:													
liquid flow, ml/h	2102.00	2533.00	2113.00	2303.00	2251.00	2189.00	2003.00	1790.00	2046.00	2320.00	2565.00	2016.00	2114.00
fluid passage rate, %/h	3.29	4.70	3.88	5.14	3.85	3.41	4.46	3.40	3.73	3.27	2.81	3.32	3.24

[d] These values are based on the use of markers.

[e] These values are based on actual dry matter content of duodenal chyme.

Table 4. Effect of Type of Grain on Mean Digestive Tract Measurements in Feedlot Steers

Item	Diets									
	WSC	WO	RC	RW	RM	RO	RB	SFW	SFM	SFC
Ruminal pH	6.63	6.68	6.64	6.59	6.60	6.69	6.67	6.56[a]	6.32[b]	6.39[b]
Duodenal pH	2.71	3.17	2.70[a]	2.63[ab]	3.08[b]	2.94[ab]	2.75[ab]	2.74	2.71	2.71
Ileal pH	7.63	8.13	7.62	7.86	7.75	8.06	7.95	7.82	7.67	7.75
Fecal pH	6.48[a]	6.97[b]	6.35[b]	6.68[c]	5.97[a]	6.78[c]	6.68[c]	6.84	6.55	6.66
Ruminal ammonia-N mg/dl	8.33	9.97	8.00[a]	17.45[b]	7.99[a]	9.82[a]	15.12[b]	14.77[b]	4.56[a]	2.13[a]
Ruminal fluid,										
passage rate, %/h	3.83	3.92	3.66	3.93	3.92	4.26	5.29	4.19	3.30	4.11
volume, liter	63.80	107.50	70.80	70.50	55.90	82.10	72.90	79.10	48.10	64.10
outflow, ml/h	2136.00[a]	4056.00[b]	2452.00[ab]	2655.00[ab]	1898.00[a]	3221.00[b]	3235.00[ab]	2312.00	1592.00	2421.00
Particulate passage rate, %/h	2.78	2.83	2.38	2.34	1.82	1.65	1.33	2.66	1.80	2.36
Flow to duodenum[d]:										
dry matter, g/h	112.50	113.80	93.10[a]	100.40[ab]	110.00[ab]	125.30[b]	91.30[a]	88.30	101.10	96.80
dry matter, %	6.12[b]	3.21[a]	4.00	4.25	5.32	4.27	3.11	4.57	5.64	4.35
Flow to duodenum[e]:										
liquid flow, ml/h	2533.00	2565.00	2102.00	2189.00	1790.00	2320.00	2016.00	2003.00	2046.00	2113.00
fluid passage rate, %/h	4.70	2.81	3.29	3.41	3.40	3.27	3.32	4.46	3.73	3.88

[d] These values are based on the use of markers.

[e] These values are based on actual dry matter content of duodenal chyme.

Mean duodenal pH was .40 greater (P<.40; SE=.18) in steers fed 35C compared to steers fed RC. Aguirre (1984) also noted a trend toward increased duodenal pH with a greater moisture content of corn grain. Among the types of grain fed, steers ingesting RM had greater (.38) duodenal pH than steers consuming RC (P<.05; SE=.18). Possibly the tannins in RM which protect the grain from intestinal digestion maintain an elevated pH.

While no differences in ileal pH were detected, fecal pH was affected by both the method of processing and type of grain. Fecal pH with both the SFC and SFM diets were greater (.31 and .58) than with the RC and RM diets (P<.007; SE=.11). This may be attributed to the greater post-ruminal and total tract digestibilities with the steam flaked diets. Wheeler and Noller (1977) noted that low fecal pH was associated with large amounts of starch in feces of cattle fed high concentrate rations. Comparing across grains, fecal pH of steers fed RC was less (.34, .43, and .33; P<.03) than in steers fed RW, RO, or RB (SE=.12, .12, and .14). Steers fed WSC had lower (.49) fecal pH than steers fed whole oats (P<.007; SE=.17). These differences are probably due to differences in particle size and total tract digestion. Steers consuming RM had a lower (.38, .81 and .71) fecal pH than when consuming RC, RO, and RB (P<.001; SE=.11, .16 and .18). High tannin concentrations and physical form of the rolled milo may inhibit intestinal

digestion contributing to greater amounts of fecal starch and the reduced fecal pH.

Ruminal ammonia concentrations were 5.86 mg/dl less when SFC diets were ingested compared with RC, WSC, 25C or 35C diets ($P<.003$; SE=1.82, 1.82, 2.58 and 2.58). Cole et al, (1976a) also noted greater ammonia concentrations with RC than SFC and speculated heat treatment of corn during steam processing denatured some of the corn protein rendering it less soluble in the rumen and increasing ruminal escape. Galyean et al. (1976) reported that less of the total corn N was soluble in steam flaked than dry rolled corn (8% vs 12% respectively). The reduced ruminal ammonia concentration with the SFC also could be attributed to increased use of ammonia nitrogen for synthesis of microbial protein. Microbial nitrogen flow to the duodenum tended to be greater for the SFC diet (41.8 g/d) than with the RC (27.5 g/d), WSC (30.8 g/d), 25C (33.2 g/d) or 35C ration (31.9 g/d).

Among the grains, wheat (both rolled and steam flaked) and barley had greater ($P<.03$) ruminal ammonia concentrations than corn, milo or oats. Oltjen et al. (1967), Fulton et al. (1979), and Axe et al. (1987) noted more rapid fermentation and increased ruminal ammonia nitrogen concentrations with wheat diets than with other cereal grains.

Fluid passage rate tended to be affected by the method of processing but not by the type of grain. Steers fed RC diets had 1.7% lower fluid passage rates ($P<.01$; SE=.65)

than steers fed 25C diets. Faster rates (1.41%) were noted ($P<.04$; SE=.65) with the 25C diets than with the 35C diets. Aguirre (1984) reported slower rates of passage and a shift towards increased ruminal digestion as the moisture level of the diets increased. Rumen volumes were not different ($P>.05$) in this trial. However, fluid passage rates in our study were negatively related with rumen volumes ($r=-.63$; $P<.0001$). Axe et al. (1987) detected no differences in rumen volumes between wheat and milo, whereas, Galyean (1977) reported inconsistent effects on rumen volumes with various particle sizes of corn grain. Ruminal outflow rates with WO and RO were 1919 and 1323 ml/h faster ($P<.006$ and $P<.05$) than with WSC and RM, respectively (SE=661 and 637). Miller et al. (1986) reported faster liquid flow rates with oat than corn or milo diets. No significant differences were noted in particulate fraction passage rates in our study, but dry matter flow to the duodenum was affected by the type of grain. Rolled oats exited the rumen in greater quantities (32 and 34 g/h) than rolled corn or barley ($P<.007$; SE=10.5 and 11.7) which could be ascribed to differences in particle size. When duodenal flow was expressed as percent dry matter, WSC had 2.1% more dry matter exiting the rumen than RC ($P<.02$; SE=.88) and WO had 2.9% greater dry matter exit than WSC ($P<.04$; SE=1.4).

Ruminal fluid outflow and percentage dry matter flow to the duodenum discussed above were calculated based on the liquid passage marker, CoEDTA, which rely on the accu-

racy of marker techniques and require frequent sampling to estimate ruminal passage. One alternative method to calculate ruminal fluid passage is from the quantity of wet matter entering the duodenum based on the passage rate marker, chromic oxide.

Liquid flow to the duodenum and fluid passage rate, calculated in this manner exhibited no response ($P>.05$) to the method of grain processing or the type of grain. Although patterns were similar, flow rates calculated from chromic oxide were 2 to 38 percent smaller than the flow rates predicted from ruminal sampling following dosing Co-EDTA (Figure 1). These two flow rates were weakly correlated ($r=.13$; $P<.30$).

Figure 2 shows the relationship between the liquid flow to the duodenum (expressed as a fraction of the rumen volumes) and the ruminal fluid and particulate passage rates. The liquid flow to the duodenum and ruminal fluid passage rate were correlated as shown by the upsloping line ($r=.61$; $P<.0001$). Calculating ruminal fluid passage by means of the amount and percentage of duodenal dry matter might be a reliable estimate of ruminal passage when ruminal pool size is known. However, duodenal flow (calculated from dry matter flow and dry matter content) and ruminal particulate passage appeared to be only weakly related ($r=.13$; $P<.32$).

Absorption or secretion of liquid between the rumen and duodenum will vary with factors other than dry matter

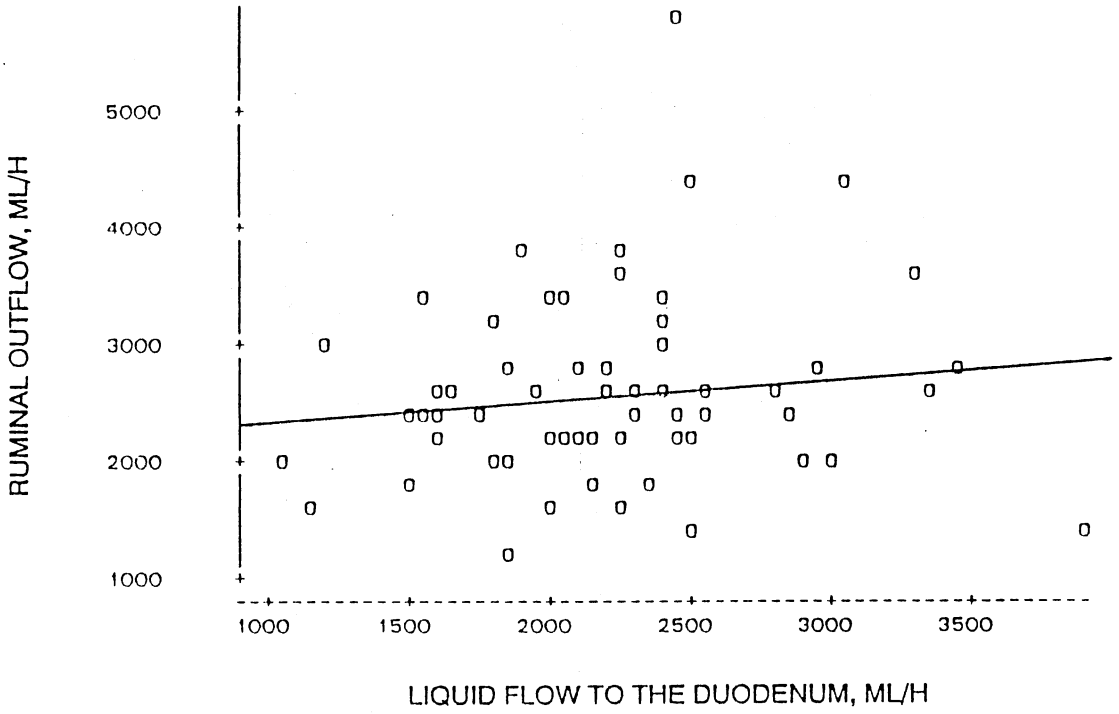

Figure 1. Ruminal Outflow (0) vs Liquid Flow to the Duodenum (based on Cr content)

O=2140.394 + .188 (liquid flow to the duodenum, ml/h); r=.13; P<.30

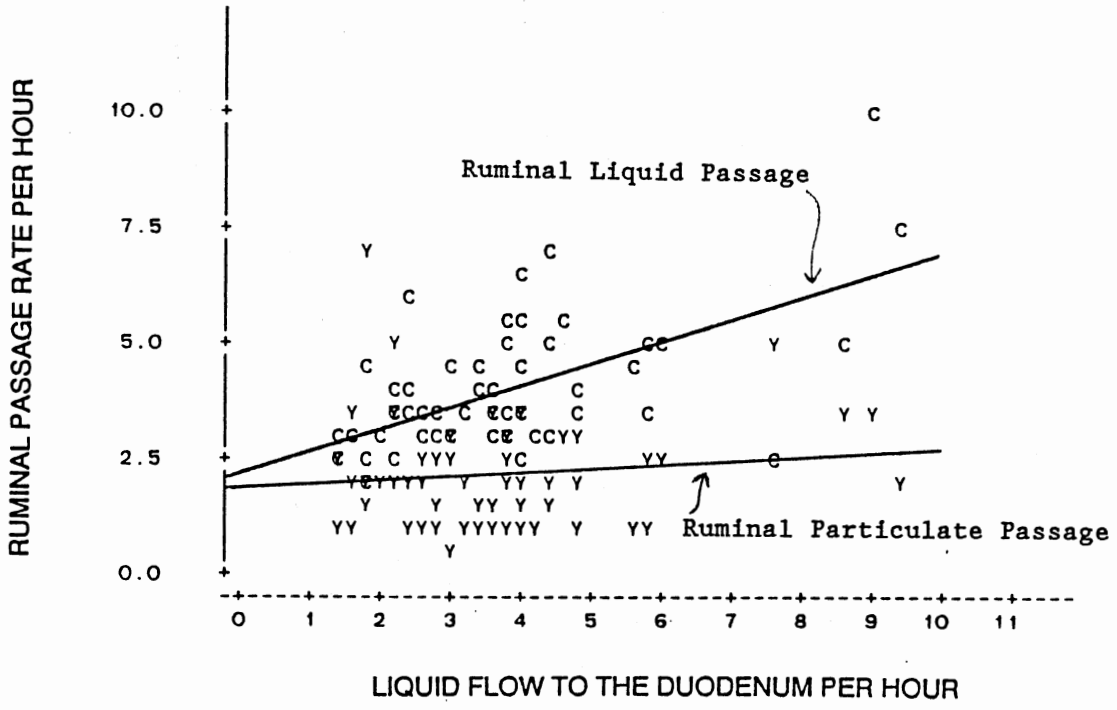

Figure 2. Ruminal Liquid (C) and Particulate Passage Rates (Y) vs Liquid Flow to the Duodenum (based on Cr content)

C=2.190 + .484 (liquid flow to the duodenum per hour); r=.61; P<.001

Y=1.831 + .082 (liquid flow to the duodenum per hour); r=.13; P<.32

content. Zinn et al. (1981) reported that duodenal chyme may be biologically adjusted to maintain a concentration of crude protein of 100 g liquid per g of protein. The mean in our study was 97.2 g liquid per g of protein. Regression of duodenal flow of chyme against flow of N (Figure 3) revealed a positive correlation ($r=.63$; $P<.0001$). Flow of N may be controlling ruminal outflow, may stimulate HCl input from the abomasum, or may be altering abomasal absorption through osmotic pressure differences.

Method of processing affected adjusted ruminal organic matter digestion of milo (Table 5). SFM had 9.9% more organic matter digested ruminally than RM ($P<.03$; SE=4.47). Rahnema et al (1987) noted that compared with dry rolled milo, steam flaked milo increased the apparent ruminal digestibility of organic matter (58.5 vs 35%). Steam flaked corn had 10% greater adjusted ruminal organic matter digestion than WSC diets ($P<.05$; SE=4.87). Flaking ruptures some of the starch granules and increases the rate of digestion. Ruminal fluid passage rates also tended to be faster with rolled milo and steam flaked corn. With faster passage out of the rumen, one would expect extent of digestion to decrease. This matches extent of OM digestion for milo but not for corn processing.

Across grain types (Table 6), greater adjusted ruminal organic matter digestion ($P<.02$) occurred in steers fed RC and RW diets compared with RM and RO rations. Greater adjusted ruminal digestion (18.5%) occurred in steers eating

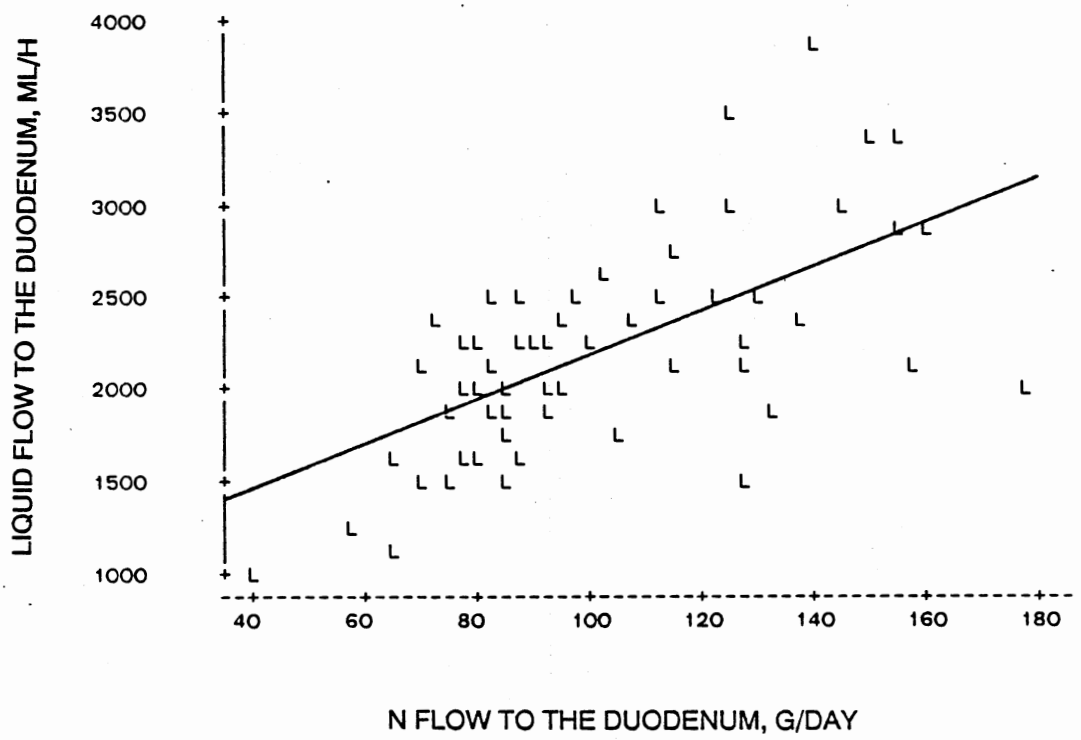

Figure 3. Liquid Flow to the Duodenum (L) vs N Flow

L=973.527 + 12.29 (N flow to the duodenum, g/day); r=.63; P<.0001

Table 5. Effect of Method of Processing on Organic Matter Digestion in Feedlot Steers

Item	Diets												
	RC	WSC	SFC	25C	35C	RW	SFW	RM	SFM	RO	WO	RB	SRB
Intake, g/d	4126.0[ac]	4133.0[cd]	4017.0[b]	4068.0[abc]	4041.0[bd]	4119.0[a]	4238.0[b]	4054.0	4050.0	4092.0	4104.0	4039.0[a]	4154.0[b]
Leaving abomasum, g/d													
total	1810.0	2173.0	1864.0	1894.0	1809.0	1914.0	1675.0	2269.0	1982.0	2476.0	2171.0	1742.0	1790.0
microbial	280.0[a]	304.0[ab]	431.0[b]	350.0[ab]	360.0[ab]	533.0[a]	335.0[b]	282.0	372.0	255.0	290.0	331.0	251.0
Ruminal digestion,													
% unadjusted	55.7	45.8	52.2	52.7	53.9	53.4	60.0	43.1	51.0	40.0	46.7	56.8	56.2
% adjusted[a]	62.6[ab]	53.5[b]	63.4[a]	61.4[ab]	63.0[ab]	66.7	68.0	50.1[b]	60.0[a]	46.3	53.8	64.9	62.4
Ruminal digestion,													
% of total, unadjusted	65.9	55.5	61.0	60.6	61.2	64.9	71.7	57.1	60.2	61.5	68.7	72.3	71.7
% of total, adjusted[e]	74.8	67.3	74.9	71.5	72.4	82.3	81.6	66.7	72.0	69.5	78.3	81.7	78.8
Leaving ileum, g/d	845.0	714.0	814.0	934.0	811.0	885.0	809.0	1133.0	989.0	1292.0	1420.0	938.0	699.0
Small intestine digestion,													
% of entering	38.5	48.0	51.5	27.3	44.2	24.9	46.1	45.6	32.7	35.4	20.3	28.3	47.8
Feces, g/d	727.0[a]	980.0[b]	618.0[ad]	645.0[ac]	573.0[cd]	793.0	704.0	1030.0[a]	740.0[b]	1264.0	1297.0	782.0	794.0
Hindgut digestion,													
% of entering	22.1	8.3	7.3	32.8	31.7	22.3	6.8	32.6	37.1	-2.4	2.1	8.2	-6.0
Post-ruminal digestion,													
% of entering	52.8	51.5	55.3	55.9	60.3	39.3	48.3	48.7	53.2	37.2	27.0	41.8	46.3
Total tract digestion,													
%	82.2[b]	75.5[a]	84.2[b]	83.8[b]	85.4[b]	81.1	83.3	74.1[a]	81.6[b]	69.6	68.7	80.8	80.8

[e] Adjusted for microbial organic matter.

Table 6. Effect of Type of Grain on Organic Matter Digestion in Feedlot Steers

Item	Diets									
	WSC	WO	RC	RW	RM	RO	RB	SFW	SFM	SFC
Intake, g/d	4133.0	4104.0	4126.0[a]	4119.0[ab]	4054.0[b]	4092.0[ab]	4039.0[ab]	4238.0[b]	4050.0[a]	4017.0[a]
Leaving abomasum, g/d										
total	2173.0	2171.0	1810.0[a]	1914.0[abc]	2269.0[bc]	2476.0[b]	1742.0[ac]	1675.0	1982.0	1864.0
microbial	304.0	290.0	280.0[ac]	533.0[b]	282.0[c]	255.0[c]	331.0[abc]	335.0	372.0	431.0
Ruminal digestion,										
% unadjusted	45.8	46.7	55.7[a]	53.4[abd]	43.1[bc]	40.0[cd]	56.8[ab]	60.0	51.0	52.2
% adjusted[a]	53.5	53.8	62.6[a]	66.7[a]	50.1[bc]	46.3[c]	64.9[ab]	68.0	60.0	63.4
Ruminal digestion,										
% of total, unadjusted	55.5	68.7	65.9	64.9	57.1	61.5	72.3	71.7	60.2	61.0
% of total, adjusted[e]	67.3	78.3	74.8	82.3	66.7	69.5	81.7	81.6	72.0	74.9
Leaving ileum, g/d	714.0[a]	1420.0[b]	845.0[a]	885.0[abc]	1133.0[abc]	1292.0[b]	938.0[ac]	809.0	989.0	814.0
Small intestine digestion,										
% of entering	48.0	20.3	38.5	24.9	45.6	35.4	28.3	46.1	32.7	51.5
Feces, g/d	980.0[a]	1297.0[b]	727.0[ac]	793.0[c]	1030.0[bd]	1264.0[d]	782.0[abc]	704.0	740.0	618.0
Hindgut digestion,										
% of entering	8.3	2.1	22.1[b]	22.3[ab]	32.6[b]	-2.4[a]	8.2[ab]	6.8[ab]	37.1[b]	7.3[a]
Post-ruminal digestion,										
% of entering	51.5[b]	27.0[a]	52.8[b]	39.3[a]	48.7[ab]	37.2[a]	41.8[ab]	48.3	53.2	55.3
Total tract digestion, %	75.5[b]	68.7[a]	82.2[b]	81.1[b]	74.1[a]	69.6[a]	80.8[b]	83.3	81.6	84.2

[e] Adjusted for microbial organic matter.

RB compared to RO (P<.003; SE=5.82). Axe et al. (1987) noted greater ruminal organic matter digestion with wheat than milo, and Miller et al. (1986) observed greater dietary organic matter digested in the rumen with corn, wheat, oats, or barley than with milo. The lower value for oats is difficult to explain though total tract OM digestion also was lower for oats and milo.

Total tract organic matter was affected by the method of grain processing. As expected, steers fed RC or SFC had greater total tract digestion than steers fed WSC (P<.003; SE=2.04). Steers consuming high moisture corn had greater total organic matter digestion than steers consuming WSC (P<.003; SE=2.63). Steers consuming RM had lower (7.5%) total organic matter digestion than steers fed SFM (P<.0002; SE=1.8). By fracturing the kernel, flaking will increase the surface area for digestion by microbes and digestive enzymes. In addition, flaking ruptures some of the starch granules which increases the rate of digestion. Whole grain which escapes ruminal digestion usually passes through the remaining intestinal tract of ruminants unscathed (Rust, 1983).

Among the types of grains, total tract organic matter digestion with RC, RW and RB were greater (P<.04) than with the RM and RO diets. Within whole grains, WSC had 6.8% greater total organic matter digestion than RO (P<.03; SE=2.98). Maxson et al. (1973) attributed lower energy di-

gestibilities by steers fed sorghum diets to their tannin content.

Adjusted ruminal organic matter digestion, when expressed as a percentage of total tract digestion, did not vary with the method of grain processing or type of grain, indicating that increased ruminal organic matter digestion tended to parallel increased total tract digestion. Adjusted ruminal organic matter digestion and total tract digestion were related positively ($r=.61$; $P<.0001$).

Although post-ruminal organic matter digestion, as a percentage of duodenal OM flow, did not vary with the method of processing, it was affected by the type of grain. Post-ruminal digestion was 24.4% greater with WSC diets than with WO ($P<.02$; $SE=10.02$). This can be attributed primarily to increased small intestine digestion ($P<.10$) with the WSC diets. However, no significant differences ($P>.05$) were observed in small intestine digestion, as a percentage of organic matter entering the small intestine. Fiber components of WO may have inhibited enzymatic attack post-ruminally. Rolled corn had greater (13.6 and 15.6%) post-ruminal digestion compared to RW and RO ($P<.05$). More RC (24%) and RM (35%) was digested in the large intestine and cecum than with the rolled oat diet ($P<.04$). Galyean (1977) reported that intestinal digestion was greater when corn was fed whole than when ground to other particle sizes. This may be attributed to greater ruminal escape of particles of an attackable size. Though differences in

rate of particulate passage through the post-ruminal tract might be involved (Owens et al., 1986), this parameter was not measured.

Adjusted ruminal N digestion (Table 7) was 21.3% less in steers fed SFM compared with steers fed RM ($P<.04$; SE=10.23). Ramirez et al. (1985) noted steam flaking should decrease particle size and increase extent of ruminal fermentation of grain, but these effects for protein could be compensated by decreases in protein solubility. Ruminal starch digestion was related positively to ruminal N digestion ($r=.24$; $P<.06$), but ruminal pH was significantly lower ($P<.0005$) in steers consuming SFM compared to the consumption of RM. Weakly (1983) noted that lower ruminal pH may enhance ruminal protein bypass of certain feedstuffs. Wholt et al. (1973) noted as pH increased from 5.5 to 7.5, mean solubility of protein feeds incubated was increased from 27 to 57%, with most of the differences in N solubility apparent between 5.5 and 6.5.

Among the grains (Table 8), adjusted ruminal N digestion was 36.4% greater with steers eating WO compared with WSC diets ($P<.04$; SE=16.9). Because the passage rates were similar, reduced mastication and rumination with WSC may be responsible. Ruminal N digestion was enhanced in steers consuming wheat compared to steers ingesting corn or milo in both the rolled ($P<.03$) and steam flaked forms ($P<.007$). Hibberd et al. (1985) previously reported lower ruminal digestion of protein in milo grain as reflected both by lower

Table 7. Effect of Method of Processing on Nitrogen Digestion in Feedlot Steers

Item	Diets												
	RC	WSC	SFC	25C	35C	RW	SFW	RM	SFM	RO	WO	RB	SRB
Intake, g/d	78.2[b]	76.8[b]	70.3[a]	77.8[b]	78.9[b]	103.3	105.7	81.2	81.4	91.0[a]	87.1[b]	98.6	99.3
Leaving abomasum, g/d													
total N	93.9	108.4	105.9	99.7	95.3	116.8	99.0	95.6[a]	120.2[b]	92.5	85.5	87.2	96.9
microbial N	27.5[a]	30.8[ab]	41.8[b]	33.2[ab]	31.9[ab]	52.4[a]	30.5[b]	24.6	31.5	25.1	25.9	31.5	24.5
ammonia N	4.7[ab]	5.8[a]	4.3[b]	5.1[ab]	4.5[ab]	7.6	6.7	3.8	3.6	4.7	5.2	5.2	5.4
rumen by-pass feed N	61.7	71.7	59.8	61.4	59.0	56.8	61.8	67.2[a]	85.1[b]	62.7	54.4	50.5	67.1
Ruminal digestion,													
% unadjusted	-21.2[a]	-49.2[b]	-57.2[b]	-29.7[ab]	-23.1[ab]	-8.0	12.3	-19.5[b]	-47.9[a]	-7.4	-1.7	6.0	-4.1
% adjusted[c]	20.6	.3	13.0	20.5	23.7	49.5	45.1	15.5[b]	-5.8[a]	28.7	36.7	46.9	30.4
by-pass feed N, %	79.4	99.7	87.0	79.5	76.3	50.5	54.9	84.5[a]	105.8[b]	71.3	63.3	53.1	69.6
Microbial efficiency,													
g microbial N/kg OM													
truly digested in rumen	12.1[a]	15.0[ab]	17.6[b]	15.5[ab]	14.5[ab]	19.5[b]	9.4[a]	13.7	15.2	12.7	12.5	12.9	10.7
Ruminal ammonia-N, mg/dl	8.0[b]	8.3[b]	2.1[a]	10.5[b]	10.3[b]	17.5	14.8	8.0	4.6	9.8	10.0	15.1	13.0
Ruminal digestion,													
% of total, unadjusted	-48.8[b]	-254.4[a]	-88.4[b]	-61.7[b]	-50.2[b]	-.8	35.4	-38.1	-98.4	-22.7	-20.8	-8.2	-18.9
% ot total, adjusted[c]	25.5[b]	-95.6[a]	16.4[b]	22.9[b]	25.9[b]	71.3	59.6	28.9	-13.7	36.1	44.5	54.8	36.4
Leaving ileum, g/d	28.1	25.2	34.0	30.9	23.8	29.5	27.7	31.5	33.1	27.7	28.3	26.3	26.7
Small intestine digestion,													
% of entering	52.1	51.2	40.1	33.8	55.9	53.2	50.6	59.4	61.9	53.9	48.2	52.3	59.0
Feces, g/d	25.2[b]	37.3[a]	19.7[b]	23.0[b]	20.6[b]	24.4	20.0	31.6	30.3	25.7	25.4	23.2	23.8
Hindgut digestion,													
% of entering	20.4[b]	-66.3[a]	21.0[b]	26.4[b]	28.3[b]	29.2	20.1	20.1	21.2	11.5	15.9	18.9	10.3
Post-ruminal digestion,													
% of entering	58.0	50.7	58.4	58.3	64.5	52.2	66.2	48.0	66.3	59.0	54.4	56.7	63.5

Table 7. (Continued)

Item	Diets												
	RC	WSC	SFC	25C	35C	RW	SFW	RM	SFM	RO	WO	RB	SRB
Total tract digestion, %	67.2[a]	47.2[b]	70.3[a]	69.4[a]	73.1[a]	79.1	82.7	60.1	62.5	69.9	69.4	74.6	73.8
Expected total tract digestion, %[d]	64.3	63.8	62.3	64.6	65.0	70.1	69.8	65.6	65.6	67.3	66.4	69.2	68.8

[c] Adjusted for microbial and ammonia nitrogen.
[d] Calculated from the crude protein of the diet by NRC (1978).

Table 8. Effect of Type of Grain on Nitrogen Digestion in Feedlot Steers

Item	Diets									
	WSC	WO	RC	RW	RM	RO	RB	SFW	SFM	SFC
Intake, g/d	76.8[a]	87.1[b]	78.2[a]	103.3[b]	81.2[c]	91.0[d]	98.6[b]	105.7[c]	81.4[b]	70.3[a]
Leaving abomasum, g/d										
total N	108.4	85.5	93.9[a]	116.8[b]	95.6[ab]	92.5[ab]	87.2[ab]	99.0	120.2	105.9
microbial N	30.8	25.9	27.5[b]	52.4[a]	24.6[b]	25.1[b]	31.5[b]	30.5	31.5	41.8
ammonia N	5.8	5.2	4.7[b]	7.6[a]	3.8[b]	4.7[b]	5.2[b]	6.7[a]	3.6[b]	4.3[b]
rumen by-pass feed N	71.7	54.4	61.7	56.8	67.2	62.7	50.5	61.8[ab]	85.1[a]	59.8[b]
Rumen digestion,										
% unadjusted	-49.2[a]	-1.7[b]	-21.2	-8.0	-19.5	-7.4	6.0	12.3[b]	-47.9[a]	-57.2[a]
% adjusted[e]	.3[a]	36.7[b]	20.6[a]	49.5[b]	15.5[a]	28.7[ab]	46.9[ab]	45.1[b]	-5.8[a]	13.0[a]
by-pass feed N, %	99.7[a]	63.3[b]	79.4[b]	50.5[a]	84.5[b]	71.3[ab]	53.1[ab]	54.9[b]	105.8[a]	87.0[a]
Microbial efficiency,										
g microbial N/kg OM										
truly digested in rumen	15.0	12.5	12.1[a]	19.5[b]	13.7[ab]	12.7[ab]	12.9[ab]	9.4[a]	15.2[ab]	17.6[b]
Ruminal ammonia-N, mg/dl	8.3	10.0	8.0[a]	17.5[b]	8.0[a]	9.8[a]	15.1[b]	14.8[b]	4.6[a]	2.1[a]
Ruminal digestion,										
% of total, unadjusted	-254.4[a]	-20.8[b]	-48.8	-.8	-38.1	-22.7	-8.2	35.4[b]	-98.4[a]	-88.4[a]
% of total, adjusted[e]	-95.6[a]	44.5[b]	25.5	71.3	28.9	36.1	54.8	59.6[b]	-13.7[a]	16.4[ab]
Leaving ileum, g/d	25.2	28.3	28.1	29.5	31.5	27.7	26.3	27.7	33.1	34.0
Small intestine digestion,										
% of entering	51.2	48.2	52.1	53.2	59.4	53.9	52.3	50.6	61.9	40.1
Feces, g/d	37.3[a]	25.4[b]	25.2	24.4	31.6	25.7	23.2	20.0[a]	30.3[b]	19.7[a]
Hindgut digestion,										
% of entering	-66.3[a]	15.9[b]	20.4	29.2	20.1	11.5	18.9	20.1	21.2	21.0
Post ruminal digestion,										
% of entering	50.7	54.4	58.0	52.2	48.0	59.0	56.7	66.2	66.3	58.4

Table 8. (Continued)

Item	Diets									
	WSC	WO	RC	RW	RM	RO	RB	SFW	SFM	SFC
Total tract digestion, %	47.2[a]	69.4[b]	67.2[a]	79.1[b]	60.1[a]	69.9[ab]	74.6[ab]	82.7[b]	62.5[a]	70.3[a]
Expected total tract digestion, %[f]	63.8	66.4	64.3	70.1	65.6	67.3	69.2	69.8	65.6	62.3

[e] Adjusted for microbial and ammonia nitrogen.
[f] Calculated from the crude protein of the diet by NRC (1978).

ruminal ammonia concentrations and greater ruminal escape of dietary protein.

Ruminal escape N percentages, being the inverse of adjusted ruminal N digestion, were greater for SFM than RM and lower for wheat than corn or milo. Increased N escape from SFM was reported by Hinman and Johnson (1974). Zinn (1987) and Prigge et al. (1978) also observed increased passage of feed N to the small intestine as a result of steam flaking. In analyzing the two high moisture levels of corn, one might have expected lower escape values because the protein in these grains should be solubilized during the fermentation process. However, Aguirre (1984) found no differences in protein bypass with high moisture grains and reasoned that the nitrogen solubilized during the fermentation process is the same fraction which normally is attacked and digested in the rumen. Though quantitatively minor, some of the soluble protein from high moisture corn, being microbial, might escape digestion in the rumen and pass to the small intestine.

With corn, our escape values for N ranged from 76.3% to 99.7% depending upon the extent of processing. Values reported from other researchers are 50%, 30 to 49%, 67 to 74%, and 58 to 73% (INRA, 1978; ARC, 1980; Madsen and Hvelplund, 1985; and NRC, 1985). Our ruminal escape values for wheat were 50.5% and 54.9% for RW and SFW, considerably greater than the 16 to 20% ruminal escape cited by Madsen and Hvelplund (1985). In our trial, escape N values for RM

and SFM were 84.5% and 105.8%. The ARC (1980) and NRC (1985) list ruminal escape values of 50 to 69% and 29 to 69%, respectively. Our values for RO and WO were 71.3 and 63.3%; whereas, INRA (1978) cited 40% and Madsen and Hvelplund (1985) listed only 16% ruminal escape N. With barley, we noted ruminal escape values of 53.1% and 69.6% for RB and SRB. Values for barley have varied (35%; 17 to 31%; 26 to 40%; and 14 to 28%) with other researchers (INRA, 1978; ARC, 1984; Madsen and Hvelplund, 1985; and NRC, 1985). Spicer et al. (1986) reported ruminal N escape for rolled barley was twice that of rolled milo or corn.

Comparisons of ruminal escape values tend to be overwhelming and confusing because of the multitude of factors to be considered. Some of these factors include species consuming the cereal grain, level of feed intake, method of cereal grain processing, particle size of the cereal grain, rumen volumes, and rate of particulate and fluid passage. To facilitate comparison of ruminal N escape, each of these factors should be defined. Without this information, comparisons at the best are very difficult and, at the worst, meaningless.

Rolling, steam flaking, or fermenting corn increased total N digestion by at least 20 percentage points above whole corn ($P<.004$). Some of this difference is attributable to greater ($P<.0001$) hindgut digestion (or less hindgut microbial protein synthesis) with rolled, steam flaked, or fermented corn than whole corn. Hindgut N di-

gestion and total tract N digestion were related positively ($r=.63$; $P<.0001$). Cole et al. (1976a) noted total N digestibility to be greater with steam flaked than rolled corn. Fracture of the kernel to enhance starch digestion should expose the protein in the grain to greater microbial and enzymatic attack. Across all treatments, total tract starch digestion was related positively to total tract N digestion ($r=.49$; $P<.0001$). Part of the benefit of steam processing and flaking on protein utilization may be due to greater ruminal synthesis of higher quality bacterial protein which may be used in the lower gastrointestinal tract without markedly affecting total protein digestion (Rahnema et al., 1987) and to increased starch digestion which decreases the drain on non-specific N for microbial protein synthesis in the large intestine.

Values for total tract N digestion in our trial were compared with expected values calculated from equations of the NRC (1978). Most of our values were consistently greater than the predicted values except for WSC which was considerably lower than the NRC values. This would suggest that total tract starch digestion might be lower in WSC and, thereby, inhibit N digestion. When our values for total tract starch digestion were contrasted with the values reported by Owens et al. (1986), our values were consistently greater. However, total tract starch digestion for WSC was lower than for other forms of corn for both our values and the values reported by Owens et al. (1986).

Differences in N and starch digestion with WSC may be attributed to both differences in particle size and the lack of physical disruption of the starch-protein matrix.

Among the grains, total tract N digestion was 22.2% greater with the WO than the WSC diets ($P<.01$; SE=8.04) and again may be due to differences both in ruminal N and hindgut starch digestion ($P<.0001$). As with ruminal digestion, total tract N digestion was greater ($P<.02$) with rolled and steam flaked wheat compared to rolled or steam flaked milo and corn. This increase in total N digestion can be attributed completely to increased ruminal N digestion. The correlation between total tract N digestion and adjusted ruminal N digestion was positive ($r=.60$; $P<.0001$). Both Waldo (1973) and Spicer et al. (1986) noted that total tract N digestion was lower for milo than corn or barley diets and had attributed the difference to reduced feed degradation in the rumen.

Ruminal N digestion, expressed as a percent of total, was less ($P<.003$) among steers fed WSC compared to RC, SFC, 25C or 35C diets. This is attributable both to increased ruminal escape and increased microbial synthesis in the hindgut of WSC. A similar difference was evident ($P<.002$) with steers fed WSC versus WO. Availability of starch post-ruminally was greater with the WSC diet. As greater quantities of starch reached the cecum and large intestine, increased microbial protein synthesis led to a negative N digestion in the hindgut. Thomas and Rook (1981) observed

that if intestinal digestibility was low, fermentation in the cecum and colon led to loss of N as ammonia. Ruminal N digestion (as a percent of total) was lower ($P<.04$) with steam flaked milo than with steam flaked wheat; this is attributed to differences in ruminal N digestion.

No differences ($P>.05$) in small intestinal or post-ruminal N digestion were evident, with all values between 40 to 59%, slightly lower than the 62% mean suggested by the NRC (1985). Cole et al. (1976a) noted no differences in post-ruminal digestion between steers fed dry rolled and steam flaked corn. Spicer et al. (1986) reported similar post-ruminal N digestibilities for rolled corn, rolled barley, and rolled milo, whereas, Miller et al. (1986) found that intestinal N digestibility of milo was 68% lower than with corn, wheat, oats, or barley. Hibberd (1982) reported greater intestinal N digestion (63.4 vs 61.1 and 58.0%) for dry rolled hetero-yellow milo than dry rolled red or brown milo and greater intestinal N digestion (73.1 vs 62.5%) for red reconstituted milo than brown reconstituted milo.

Microbial efficiency with the SFC diets was 5.5 g/kg greater than with the RC ration ($P<.04$; $SE=2.57$). With SFC diets, ruminal ammonia concentrations averaged only 2.13 mg/dl. Thomas and Rook (1981) noted that higher efficiencies were linked with higher ruminal ammonia concentrations, opposite of our results. The correlation between microbial efficiency and mean ruminal concentrations was very low in our study ($r=.05$; $P<.67$). Rahnema et al.

(1987) observed microbial efficiencies of 16.9 g/kg and 23.7 g/kg for steam flaked and dry rolled corn, respectively. Cole et al. (1976a) reported that at low dilution rates, ruminal microbial protein synthesis was highly dependent upon the rumen dilution rates. Galyean (1977) suggested that with increased particle size of corn grain, fluid dilution rates tended to be faster. In our study, steam flaked corn, which had a larger average particle size than RC, tended to have a faster fluid passage rate. Particles leaving the rumen may act to transport bacteria from the rumen. Relative rates of (1) microbial dilution, (2) feed removal, (3) fermentation rates and capacity, and (4) lag time for fermentation all can alter microbial output from the rumen (Goetsch and Owens, 1984).

Microbial efficiency with the RW diet was 10.1 g/kg greater than with SFW ($P<.002$; SE=3.07). Both the fluid and particulate passage rates tended to be greater with the SFW ration, opposite that expected to explain efficiency differences. Adjusted ruminal organic matter digestion and microbial efficiency were negatively related ($r=-.48$; $P<.0001$). Cole et al. (1976a) noticed greater microbial efficiencies with dry rolled and whole shelled corn than steam flaked corn. They reasoned that heat treatment of grain during steam processing would denature some of the grain protein, rendering it less soluble in the rumen and causing more rumen bypass. Less soluble N in the rumen or increased ruminal escape of N should increase microbial ef-

ficiency if the level of ammonia in the rumen is sufficient to support protein synthesis by the microbes. Reducing microbial fermentation (or increasing microbial efficiency) may prove advantageous when fermentation energy loss is large and fermented nutrients could be digested in and absorbed from the small intestine (Owens and Bergen, 1983). Galyean (1975) reported less total corn N was soluble in steam flaked than dry rolled corn (8 versus 12%, respectively).

Among the grains, microbial efficiencies with RW were 7.4 g/kg greater ($P<.01$; SE=2.80) than with RC. However, when SFC was compared with SFW the microbial efficiencies were reversed, with SFC being 8.2 g/kg greater ($P<.006$; SE=2.80). These differences may be related to differences in passage rates as well as ruminal digestion. Clark et al. (1987) concluded with various barley types that at very fast fermentation rates, microbial growth was no longer coupled to OM digestion. One could speculate this may have occurred with SFW. Spicer et al. (1986) noted no differences in microbial efficiencies among rolled corn, milo, or barley, but the percentage of bacterial N in the abomasum was greater for barley than for milo or corn diets (72 versus 47 and 53%, respectively).

Ruminal starch digestion (Table 9) was 21.4% greater for SFM than RM ($P<.0001$; SE=3.89). Hinman and Johnson (1974) reported ruminal digestion tended to be greater (4.8%) with steam flaked than rolled milo. In another

Table 9. Effect of Method of Processing on Starch Digestion in Feedlot Steers

Item	Diets												
	RC	WSC	SFC	25C	35C	RW	SFW	RM	SFM	RO	WO	RB	SRB
Intake, g/d	2959.0[b]	3011.0[b]	2936.0[b]	2404.0[a]	2492.0[a]	2835.0[a]	2626.0[b]	2770.0	2723.0	1760.0	1604.0	2529.0	2592.0
Leaving abomasum, g/d	454.0	582.0	364.0	388.0	311.0	382.0	238.0	921.0[a]	315.0[b]	194.0	129.0	279.0	217.0
Ruminal digestion, %	84.4	80.0	87.3	82.7	86.4	86.4	90.3	66.5[a]	88.0[b]	90.5	92.3	88.7	91.0
Ruminal digestion, % of total	86.8	77.8	87.8	82.0	86.9	87.2	90.2	71.9[a]	89.2[b]	93.5	97.2	91.7	93.6
Feces, g/d	91.5[c]	208.2[b]	27.2[a]	29.9[a]	15.7[a]	38.7	17.5	273.5[a]	44.4[b]	54.4	90.0	55.5	54.2
Post-ruminal digestion, % of entering	79.0	68.2	89.6	85.8	86.8	86.4	91.0	67.5	73.9	70.3[b]	19.3[a]	102.2	88.1
Expected post-ruminal digestion, % of entering[d]	73.1	75.4	87.9	89.8	--	--	--	54.8	--	--	--	--	--
Total tract digestion, %	96.7[b]	92.5[a]	99.1[c]	98.4[bc]	99.1[c]	98.8	99.1	90.1[a]	98.3[b]	97.6	95.3	98.0	98.1
Expected total tract digestion, %[d]	93.2	87.6	97.8	94.6	--	--	--	86.4	--	--	--	--	--

[d] Values reported by Owens et al. (1986).

trial (Zinn, 1987), ruminal starch digestion of corn tended to increase due to steam flaking; however, the major benefit of flaking was post-ruminal. Increased ruminal starch digestion with steam flaked grains may be attributed both to differences in particle size and fluid passage rates. Ruminal starch digestion was negatively related ($r=-.26$; $P<.04$) with fluid passage rate, but positively related ($r=.32$; $P<.009$) with rumen volume.

Comparing across the grains (Table 10), ruminal starch digestion was lower ($P<.002$) for RM than for RC, RW, RO, or RB. In a trial contrasting rolled milo, rolled corn, and steam flaked barley, Spicer et al. (1986) found that ruminal starch digestion was less for rolled milo than for corn and barley (75 versus 84 and 88%, respectively). Stock et al. (1987b) suggested that starch from rolled milo is digested slower and less completely in the rumen than starch from corn.

Total tract starch digestion was lower ($P<.002$) with WSC than with 25C, 35C, SFC, or RC diets. Turgeon et al. (1983) concluded that corn particle size did not affect the percentage or amount of starch digested ruminally or post-ruminally, but total tract starch digestion was greater ($P<.08$) for rolled than whole shelled corn diets. However, Aguirre (1984) stated that the disappearance of starch in the rumen, small and large intestine, expressed as a percent of input, increased as extent of processing increased and particle exposure increased. Galyean (1977) noted that

Table 10. Effect of Type of Grain on Starch Digestion in Feedlot Steers

Item	Diets									
	WSC	WO	RC	RW	RM	RO	RB	SFW	SFM	SFC
Intake, g/d	3011.0[a]	1604.0[b]	2959.0[d]	2835.0[cd]	2770.0[ac]	1760.0[b]	2529.0[a]	2626.0[b]	2723.0[ab]	2936.0[a]
Leaving abomasum, g/d	582.0[a]	129.0[b]	454.0[a]	382.0[ac]	921.0[b]	194.0[c]	279.0[ac]	238.0	315.0	364.0
Ruminal digestion, %	80.0	92.3	84.4[b]	86.4[b]	66.5[a]	90.5[b]	88.7[b]	90.3	88.0	87.3
Ruminal digestion, % of total	77.8[a]	97.2[b]	86.8[b]	87.2[b]	71.9[a]	93.5[b]	91.7[b]	90.2	89.2	87.8
Feces, g/d	208.2[a]	90.0[b]	91.5[a]	38.7[b]	273.5[c]	54.4[ab]	55.5[ab]	17.5	44.4	27.2
Post-ruminal digestion, % of entering	68.2[b]	19.3[a]	79.0[ab]	86.4[ab]	67.5[ab]	70.3[a]	102.2[b]	91.0	73.9	89.6
Expected post-ruminal digestion, % of entering[d]	75.4	--	73.1	--	54.8	--	--	--	--	87.9
Total tract digestion, %	92.5	95.3	96.7[b]	98.8[c]	90.1[a]	97.6[bc]	98.0[bc]	99.1	98.3	99.1
Expected total tract digestion, %[d]	87.6	--	93.2	--	86.4	--	--	--	--	97.8

[d] Values reported by Owens et al. (1986).

some degree of alteration of the whole kernel beyond mastication was necessary to maximize ruminal and total tract starch digestion.

Steers fed either SFC or 35C had 2.4% greater (P<.01; SE=.89) total tract starch digestion than steers fed RC. Similar improvements from steam flaking (Galyean, 1975; Ramirez et al., 1985; and Zinn, 1987) and high moisture ensiling (Stock et al., 1987a) have been noted by other researchers. Galyean (1977) summarized that while particle size influences starch digestibility, processing by steam flaking or high moisture methods further increased starch digestion above that ascribable to particle size reduction alone. Solubilization of the protein matrix surrounding the starch granule may make the starch more accessible to amylolytic bacteria.

Total tract starch digestibility was 8.2% greater (P<.0001; SE=.96) for the SFM diet than the RM diet. Cole et al. (1976c) reported similar differences in total tract starch digestion (99.0 vs 93.6%) when they compared steam flaked corn to rolled corn diets, respectively. Hinman and Johnson (1974) found reduced intestinal and total tract starch digestion with rolled milo and suggested that the raw starch from dry rolled milo was less accessible to enzymatic attack in the small intestine.

Among the grains, steers fed RM had lower (P<.0001) total tract starch digestion than steers eating RC, RW, RB or RO. Cattle consuming RW had 2% greater total starch di-

gestion than when ingesting RC (P<.04; SE=.97). Higher total tract starch digestion coefficients of 98, 99, and 100% have been reported previously for milo, corn, and barley based diets (Waldo, 1973), but other researchers (Spicer et al., 1986 and Stock et al., 1987) have observed lower total tract starch digestion with milo. Some of this decrease appears to be related to decreased ruminal starch degradation. Hibberd et al. (1982) explained that certain seed components, such as proteins or tannins, or other factors, such as physical accessibility might limit starch digestion.

Ruminal starch digestion, as a percent of total tract starch digestion, was 17.3% greater with SFM versus the RM diets (P<.0003; SE=4.16), primarily due to the greater ruminal digestion with SFM. Spicer et al. (1986) noted that grains extensively degraded in the rumen exhibited greater total tract starch digestibilities. Ruminal starch digestion was correlated positively (r=.78; P<.0001) with total tract starch digestion.

Ruminal starch digestion, as a percent of total tract starch digestion, was significantly lower (P<.01) for RM than RC, RO, RW, or RB diets. Axe et al. (1987) also detected this trend as milo content of the diet increased. Steers fed WO had 19.4% greater fractional ruminal starch digestibilities than when they were fed WSC rations (P<.01; SE=7.48). This is related primarily to ruminal differences and partly to lower post-ruminal starch digestibility (49%,

P<.01; SE=17.89) with the WO diet. Muntifering et al. (1981) reported that post-ruminal starch digestion from whole shelled corn rations was 90%, considerably above our mean of 68%. Ruminal starch digestion (as a percent of total) was related positively with total starch digestion (r=.66; P<.0001) but related negatively with post-ruminal starch digestion (r=-.23; P<.07). Ruminal fermentation of WSC diets is limited by microbial penetration of the kernels, which reduces substrate availability in the rumen (Rode et al., 1987).

Rolled oats had 51% more starch digested post-ruminally than WO (P<.0002; SE=12.10). As the amount of grain processing increases, post-ruminal digestion usually increases (Aguirre, 1984). Hence, particle size may limit digestion both in the rumen and intestine. Compared to RO, RB had 31.9% more (P<.01; SE=12.03) starch digested post-ruminally.

No differences (P>.05) were apparent in ruminal ADF digestion between either the method of grain processing (Table 11) or the type of grain (Table 12). However, cottonseed hulls comprised 62.9% of the ADF in the ration; the pellets and cereal grain provided the remaining 37.1% of the ADF. Similar results have been reported by other researchers (Zinn, 1987; Stock et al., 1987a; Stock et al., 1987b; and Axe et al., 1987). Rumen starch and ADF digestion were correlated positively (r =.49; P<.0001), opposite what would be expected from pH differences. Decreased ru-

Table 11. Effect of Method of Processing on Acid Detergent Fiber Digestion in Feedlot Steers

	Diets												
Item	RC	WSC	SFC	25C	35C	RW	SFW	RM	SFM	RO	WO	RB	SRB
Intake, g/d	469.0^{ab}	451.0^{ab}	410.0^{a}	487.0^{ab}	502.0^{b}	438.0	425.0	475.0	452.0	1029.0	1000.0	526.0^{a}	604.0^{b}
Leaving abomasum, g/d	323.0	379.0	361.0	342.0	359.0	382.0	356.0	351.0	366.0	762.0	660.0	386.0	399.0
Apparent ruminal digestion, %	28.9	12.8	10.6	28.4	26.9	11.3	17.3	22.6	19.4	20.1	27.0	23.7	28.2
Ruminal digestion, % of total	64.2	22.0	44.2	83.5	86.6	24.6	58.7	138.0^{b}	23.6^{a}	18.2	31.4	-5.2	22.0
Feces, g/d	289.0	334.0	339.0	304.0	263.0	416.0	345.0	343.0	329.0	607.0	605.0	327.0	357.0
Post-ruminal digestion, % of entering	4.8	14.2	9.6	-4.6	13.9	-7.6	6.1	-12.9	-6.1	19.5	2.0	25.0	15.8
Total tract digestion, %	36.8^{ab}	25.5^{ab}	21.0^{a}	33.1^{ab}	44.1^{b}	11.0	23.5	20.6	23.4	28.9	28.6	31.0	31.7

Table 12. Effect of Type of Grain on Acid Detergent Fiber Digestion in Feedlot Steers

Item	Diets									
	WSC	WO	RC	RW	RM	RO	RB	SFW	SFM	SFC
Intake, g/d	451.0[a]	1000.0[b]	469.0[b]	438.0[b]	475.0[b]	1029.0[a]	526.0[b]	425.0	452.0	410.0
Leaving abomasum, g/d	379.0[a]	660.0[b]	323.0[b]	382.0[b]	351.0[b]	762.0[a]	386.0[b]	356.0	366.0	361.0
Apparent ruminal digestion, %	12.8	27.0	28.9	11.3	22.6	20.1	23.7	17.3	19.4	10.6
Ruminal digestion, % of total	22.0	31.4	64.2	24.6	138.0	18.2	-5.2	58.7	23.6	44.2
Feces, g/d	334.0[a]	605.0[b]	289.0[a]	416.0[b]	343.0[ab]	607.0[c]	327.0[ab]	345.0	329.0	339.0
Post-ruminal digestion, % of entering	14.2	2.0	4.8	-7.6	-12.9	19.5	25.0	6.1	-6.1	9.6
Total tract digestion, %	25.5	28.6	36.8[b]	11.0[a]	20.6[a]	28.9[ab]	31.0[ab]	23.5	23.4	21.0

minal fiber digestion could retard starch digestion by preventing removal of fibrous cell structures which shield starch or by increasing the amount of particulate residues, rumen motility, and rate of exit of particles containing starch from the rumen (Goetsch and Owens, 1984). Yet, in the rumen, starch fermentation generally decreases pH which inhibits cellulose digestion when pH drops below 6. In our study, pH of ruminal samples always exceeded 6, so such inhibition is unlikely. Never-the-less, mean ruminal pH and ruminal ADF digestion were positively related ($r=.33$; $P<.007$).

Total tract ADF digestibility of 35C was 23% greater ($P<.03$; SE=9.96) than SFC. This may be partly attributed to increased ruminal digestion and a higher ruminal pH. Mean ruminal pH and total tract ADF digestion were positively correlated ($r=.40$; $P<.002$). Fibrous cell walls of corn kernels inhibit microbial and enzymatic attack (Rust, 1983). Grain processing helps to reduce such interference. Grinding will reduce the particle size, increase the surface area, and increase the rate of digestion. In addition, fermentation softens the particles (Aguirre, 1984) which increases the efficiency of mastication and exposure of grain particles to microbial enzymes. Aguirre (1984) reported that ruminal digestibility of ADF tended to be the greatest at the highest moisture level (35%), but overall, ruminal and total tract ADF digestibilities tended to decline as moisture content of the grain increased. He at-

tributed this to a lower ruminal pH from higher moisture grain; such pH effects were not evident in our trial. Other researchers (Galyean, 1975 and Cole et al., 1976c) have detected no effect of corn processing method on total tract ADF digestibility.

Among these grains, total tract digestion of ADF was lower ($P<.02$) with the RW compared with the RC or RM diets. Axe et al. (1987) noted that total tract ADF digestibilities were similar for rolled wheat and high moisture milo diets. Lower fecal pH with RM may reflect suboptimal conditions for cellulose digestion in the large intestine.

Ruminal digestion of ADF (as a percent of total tract digestion) was affected by processing but not by type of grain. Rolled milo had greater ($P<.04$) ruminal ADF digestion (as a percent of total) than SFM. The fact that ruminal ADF digestion exceeded total tract ADF digestion with the RM diet must reflect errors in sampling. Though this might alter absolute values, relative values should be realistic.

Post-ruminal digestion of ADF did not vary with the type of grain or method of processing. Negative digestibilities presumably reflect problems in duodenal sampling. Post-ruminal ADF digestion was negatively related with ruminal ADF digestion ($r=-.40$; $P<.003$). This inverse relationship reflects compensatory fiber digestion of ADF escaping fermentation in the rumen. Extent of post-ruminal

starch digestion was related positively with post-ruminal fiber digestion ($r=.28$; $P<.04$). Compensatory digestion would be expected because the cecum and large intestine possess extensive fermentation capability for both soluble carbohydrates and cellulose. As microbes of the cecum and large intestine digest ADF, this may expose more starch for fermentation to volatile fatty acids. Hence, hindgut ADF digestion should enhance starch fermentation though the reverse might not hold true when starch fermentation is extensive due to effects on pH.

Increased understanding of grain processing and type of grain on the site of digestion and rate of passage is needed to fully explain the efficiency advantages for certain processing methods and to modify processing or type of grain to maximize profit. In addition to cost and effectiveness of a particular type of grain or method of processing for cattle, additional factors must be considered when choosing a grain or processing method. Such factors include geographic availability and compatibility, roughage availability, animal health and management, level of feed intake, bunk life of the diet, and diet handling and mixing capabilities. Only when all these factors are considered fully and collectively will cattle producers be able to optimize animal performance and maximize profits.

CHAPTER IV

EFFECT OF CEREAL GRAIN TYPE AND METHOD OF PROCESSING UPON IN SITU DRY MATTER AND NITROGEN DISAPPEARANCE IN FEEDLOT STEERS

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Summary

Three ruminally cannulated steers (326 kg) were used in six 3 x 3 latin square design experiments to investigate the effect of cereal grain type and method of processing on in situ dry matter and nitrogen disappearance. Treatments included five cereal grains (oats, corn, barley, wheat and milo) processed by two or more of five methods [rolled, steam flaked, steam rolled, and ensiled (25% and 35% high moisture)]. Ruminal contents from steers fed whole shelled corn contained 7.5 and 16.6% more dry matter than fluid taken from steers consuming rolled corn or steam flaked corn. Ruminal ammonia levels were greater ($P<.05$) with rolled than with steam flaked wheat, milo, and barley and lower with rolled corn compared with rolled wheat, oat, or barley diets. Buffering capacity was not altered by

processing method but was greater with rolled barley than rolled corn diets. For ruminal dry matter disappearance, interactions were detected between the grain fed and the grain incubated in the dacron bag, which presumably was influenced by ruminal pH. Dry matter disappearance was 1.85% faster ($P<.05$) with 35% high moisture corn than with rolled corn diets and 1.99% and 2.79% faster with rolled corn and barley than rolled oats. Rates of nitrogen digestion were not affected by the type of grain but protein solubility tended to be decreased by heat processing treatments, presumably due to denaturation of the protein. Microbial nitrogen contamination in situ was relatively low (from zero to 4.78% of total residual nitrogen).

(Key Words: In Situ, Steers, Grain Processing, Grain Type, Digestibility)

Introduction

Bypassing the rumen changes the site in the digestive tract of nutrient absorption and provides one mechanism for supplementing the flow of nutrients to the intestines. Grain processing provides one potential mechanism for manipulating the quantity of dietary protein which escapes from the rumen (Chalupa, 1975).

Each feedstuff has a characteristic dry matter, nitrogen, and starch disappearance pattern in the rumen. It can be altered by adjustment of particle size and method of processing. Differential rates in dry matter disappearance

among various grains are due partly to differences in the amount and composition of protein surrounding the starch granules (Thomas et al., 1987). Heat applied or generated during grain processing can alter the extent of ruminal degradation of starch by modifying the integrity of the coat and of protein by modifying the solubility of the protein in rumen liquid.

One method to appraise rate and extent of ruminal degradation of feedstuffs is the in situ nylon bag technique. Results can vary widely among steers fed the same ration, among rations fed, duration of sample incubation, period, location in the rumen, sample size, bag cloth types, bag sizes, grains, and grain preparations (Frigoid et al., 1972).

The objectives of this trial were 1) to measure ruminal extents of in situ disappearance of dry matter and protein from commonly fed cereal grains processed by several commercial methods, 2) to assess the potential interaction between type of grain fed versus type of grain being incubated in situ, and 3) to determine the correlation between ruminal pH and in situ disappearance of dry matter and nitrogen from cereal grains.

Materials and Methods

Three European (exotic) crossbred steers (326 kg), fitted with large ruminal cannulas, were used in six 3 x 3 latin square experiments to investigate the influence of

cereal grain type and method of processing upon the extent of ruminal digestion. Each steer was vaccinated 45 days before initiation of the trial for 7-way-blackleg, 5-way-lepto, haemophilus, IBR, BVD, and PI_3 and injected with Ivermectin and Vitamin A, D_3, and B_{12}. Each animal was fed the 77% cereal grain diets discussed in Chapter III and which are described in Table 1 of this chapter.

Diets fed in latin square 1 included rolled corn (RC), rolled wheat (RW), and steam flaked corn (SFC). Latin square 2 consisted of rolled corn (RC), steam flaked wheat (SFW), and whole shelled corn (WSC). Diets in latin square three were rolled corn (RC), 25%, and 35% high moisture corn (C25 and C35). The fourth latin square utilized diets of rolled corn (RC), rolled milo (RM), and steam flaked milo (SFM). In the fifth latin square, rolled corn (RC), rolled barley (RB), and steam rolled barley (SRB) were fed. In the sixth latin square, diets contained rolled corn (RC), rolled oats (RO), and whole oats (WO). Animals were housed in 9 square meter pens and fed twice daily (0630 and 1830). Daily dry matter intake of each animal was restricted to 1.5% of the animal's initial weight.

Periods lasted 10 days with sampling on days 8 through 10 of each period. Feed samples were collected on days 8 through 10 and composited within each diet and period. At 1430 on day 8 and 0630 and 2030 on day 9 rumen samples were withdrawn via cannula. Ruminal pH was measured; then rumen fluid was strained through four layers of cheesecloth, 1 ml

Table 1. Analysis of Finishing Diets

	Diets												
Item	RC	WSC	SFC	25C	35C	RW	SFW	RM	SFM	RO	WO	RB	SRB
Crude protein, %	10.97	11.09	10.32	10.69	11.06	16.94	14.68	11.39	11.38	12.53	12.74	14.21	13.91
Starch, %	63.93	65.36	66.39	56.01	58.20	55.21	63.22	59.50	58.30	39.23	38.59	53.47	54.41
Acid detergent fiber, %	10.55	7.78	10.72	10.85	11.09	9.55	7.95	13.08	11.23	22.42	23.22	11.91	11.60
Ash, %	4.85	4.58	4.76	4.82	5.11	5.16	5.15	5.19	5.41	6.45	6.50	5.79	5.62

of 20% H_2SO_4 was added per 50 ml strained fluid, and the samples were frozen for later analysis. For ammonia analysis, 45 g of each sample was centrifuged twice at 10,000 g for 10 minutes. The supernatant fluid was analyzed for ammonia-nitrogen (Broderick and Kang, 1980).

On day 10 at 1830 (before feeding), a 200 ml aliquot of rumen fluid was withdrawn from each steer and dried at 55 C for 72 h to determine dry matter content of the rumen fluid.

To estimate buffering capacity, an additional 40 ml of strained rumen fluid was obtained 2 h postfeeding (2030 h). The pH was increased to 7.0 by the addition of .1 N NaOH. Buffering capacity was measured by titrating this mixture with .1 N HCl in pH increments of .5 to a final pH of 3.

Feed samples were ground in a Wiley mill fitted with a 2 mm screen and frozen for further analysis. Feed samples were analyzed for dry matter (DM; 90 C for 24 h), ash (600 C for 12 h), Kjeldahl nitrogen (N; AOAC, 1975), starch (MacRae and Armstrong, 1968), and crude fiber (Goering and Van Soest, 1970).

To determine in situ ruminal digestion rate, the cereal grains for each latin square were ground through a 2 mm screen. Triplicate bags containing 1.5 g of each grain were suspended in the rumen of each steer for 4, 12, or 24 h each period, beginning day 8. Bag construction, incubation and washing procedures were described previously by Weakley et al. (1983) and included securing the 50 to 70

micron pore size dacron bags with plastic covered steel wire on a weighted string. After removal from the rumen, the bags were washed for 4 min, dried for 48 h at 55 C, weighed, and Kjeldahl nitrogen (AOAC, 1975) was determined on two duplicate bags and on an empty (blank) incubated bag to determine feedstuff nitrogen disappearance.

Residues from one of the triplicate bags at 12 and 24 hours were composited within type of grain and hour of suspension across all steers in each latin square. These residues, as well as undigested substrates, were analyzed for purine content to quantitate bacterial contamination.

Bacterial contamination was calculated as percentage purine-N content of the residue minus percentage purine-N content of the feed divided by the percentage of total nitrogen of the residue. In situ digestion rates were calculated by regressing the natural logarithm of the residual nutrient against ruminal exposure time.

Data from the six 3 x 3 latin squares was pooled together and analyzed using a general linear model program. For dietary intake variables and ruminal measurements, the classes in the statistical model included latin square, steer, period, and grain fed. Least square means for the pooled data are reported. Pairwise comparisons were made to test the effect of grain processing or the effect of type of grain. Difference estimates, their probability, and standard errors are reported in the text for specific

comparisons because errors for contrasts differ with number and proximity (steer, period and squares) of observations.

A general linear model program was used to determine the interaction of type of grain being fed and the type of grain in the dacron bag. Classes included latin square, steer, period, and the grain fed - grain in the dacron bag combination. The relative intercepts and slopes of these regressions were the variables of interest. Interaction was tested within each latin square. Because certain interactions were significant, least square means and pairwise comparisons (for the method of processing and type of grain) are reported assuming that the grain being fed was rolled corn.

Results and Discussion

Intakes of specific nutrients are presented in Tables 2 and 3. Dry matter intakes of 35C, RW, and RB were slightly but significantly ($P<.05$) less (121, 154, and 110 g) than with the RC, SFW, and SRB diets (SE=47.65, 67.39, and 47.64). Within processing methods, dry matter intake of RM was 150 g less ($P<.05$; SE=67.39) than RO. Dry matter intake of SFW was 291 and 267 g greater ($P<.002$; SE=67.39) compared with SFC and SFM, respectively. Feed intake was limited to 1.5% body weight for all diets, so differences in dry matter intake primarily reflect feed sampling errors and differences in environmental humidity at the time of sampling.

Table 2. Effect of Method of Processing Upon Dietary Intake

Item	Diets												
	RC	WSC	SFC	25C	35C	RW	SFW	RM	SFM	RO	WO	RB	SRB
Dry matter, g/d	5023.0^{a}	5033.0^{ab}	4920.0^{ab}	4945.0^{ab}	4902.0^{b}	5058.0^{a}	5211.0^{b}	4956.0	4945.0	5106.0	5068.0	4991.0^{a}	5101.0^{b}
Dry matter, %	90.9^{a}	91.1^{a}	87.4^{b}	78.9^{c}	69.6^{d}	91.5	90.2	88.9^{a}	87.1^{b}	93.2	92.5	90.3	90.0
Ash, g/d	243.0^{abc}	231.0^{d}	234.0^{bd}	238.0^{bd}	251.0^{c}	261.0	268.0	257.0	267.0	331.0	331.0	289.0	287.0
Ash, %	4.8^{ab}	4.6^{a}	4.8^{ab}	4.8^{ab}	5.1^{b}	5.2	5.1	5.2	5.4	6.5	6.5	5.8	5.6
Organic matter, g/d	4779.0^{a}	4802.0^{ab}	4687.0^{ab}	4707.0^{ab}	4651.0^{b}	4797.0	4943.0	4698.0	4677.0	4776.0	4738.0	4702.0^{a}	4814.0^{b}
Organic matter, %	95.2^{ab}	95.4^{a}	95.2^{ab}	95.2^{ab}	94.9^{b}	94.8	94.9	94.8	94.6	93.5	93.5	94.2	94.4
Nitrogen, g/d	88.0	89.0	81.0	85.0	87.0	137.0	122.0	90.0	90.0	103.0	103.0	114.0	114.0
Nitrogen, %	1.8	1.8	1.7	1.7	1.8	2.7	2.3	1.8	1.8	2.0	2.0	2.3	2.2
Starch, g/d	3211.0^{d}	3285.0^{cd}	3270.0^{cd}	2767.0^{ab}	2854.0^{ac}	2789.0^{a}	3286.0^{b}	2948.0	2880.0	1985.0	1938.0	2664.0	2770.0
Starch, %	63.9^{b}	65.4^{b}	66.4^{b}	56.0^{a}	58.2^{ab}	55.2	63.2	59.5	58.3	39.2	38.6	53.5	54.4
Acid detergent fiber, g/d	529.0^{a}	395.0^{b}	529.0^{ab}	537.0^{ab}	544.0^{a}	483.0	418.0	648.0	554.0	1153.0	1183.0	593.0	590.0
Acid detergent fiber, %	10.5^{b}	7.8^{a}	10.7^{b}	10.8^{b}	11.1^{b}	9.6	7.9	13.1	11.2	22.4	23.2	11.9	11.6

Table 3. Effect of Type of Grain Upon Dietary Intake

	Diets									
Item	WSC	WO	RC	RW	RM	RO	RB	SFW	SFM	SFC
Dry matter, g/d	5033.0	5068.0	5023.0^{ab}	5058.0^{ab}	4956.0^{a}	5106.0^{b}	4991.0^{ab}	5211.0^{a}	4945.0^{b}	4920.0^{b}
Dry matter, %	91.1	92.5	90.9^{a}	91.5^{ac}	88.9^{b}	93.2^{c}	90.3^{ab}	90.2^{a}	87.1^{b}	87.4^{b}
Ash, g/d	231.0^{a}	331.0^{b}	243.0^{a}	261.0^{b}	257.0^{b}	331.0^{c}	289.0^{d}	268.0^{b}	267.0^{b}	234.0^{a}
Ash, %	4.6^{a}	6.5^{b}	4.8^{a}	5.2^{ab}	5.2^{b}	6.5^{c}	5.8^{d}	5.1^{ab}	5.4^{a}	4.8^{b}
Organic matter, g/d	4802.0	4738.0	4779.0	4797.0	4698.0	4776.0	4702.0	4943.0^{a}	4677.0^{b}	4687.0^{b}
Organic matter, %	95.4^{a}	93.5^{b}	95.2^{ab}	94.8^{bc}	94.8^{c}	93.5^{d}	94.2^{e}	94.9^{ab}	94.6^{a}	95.2^{b}
Nitrogen, g/d	89.0	103.0	88.0^{a}	137.0^{b}	90.0^{ac}	103.0^{cd}	114.0^{d}	122.0^{b}	90.0^{a}	81.0^{a}
Nitrogen, %	1.8	2.0	1.8^{a}	2.7^{b}	1.8^{a}	2.0^{ac}	2.3^{c}	2.3^{b}	1.8^{a}	1.7^{a}
Starch, g/d	3285.0^{a}	1938.0^{b}	3211.0^{c}	2789.0^{b}	2948.0^{bc}	1985.0^{a}	2664.0^{b}	3286.0	2880.0	3270.0
Starch, %	65.4^{a}	38.6^{b}	63.9^{c}	55.2^{b}	59.5^{bc}	39.2^{a}	53.5^{b}	63.2	58.3	66.4
Acid detergent fiber, g/d	395.0^{a}	1183.0^{b}	529.0^{a}	483.0^{a}	648.0^{b}	1153.0^{c}	593.0^{ab}	418.0	554.0	529.0
Acid detergent fiber, %	7.8^{a}	23.2^{b}	10.5^{a}	9.6^{a}	13.1^{b}	22.4^{c}	11.9^{ab}	7.9^{a}	11.2^{b}	10.7^{ab}

Ash intake was 12 g less with WSC than with the RC diet ($P<.05$; SE=5.47). The ash intake was greater ($P<.05$) for the 35C diet than for the 25C, SFC, or WSC diets. Across types of grains, WO provided 100 g more ash daily than WSC ($P<.0001$; SE=7.73). Rolled corn presented less ($P<.03$) ash than any of the other rolled grains. Ash intakes of RO and RB were greater ($P<.0004$) than with RW or RM; whereas, ash intake for RO was 42 g greater ($P<.002$; SE=7.73) than RB. Both SFM and SFW provided greater ash intakes ($P<.0008$; SE=7.73) than SFC. Part of these differences may be due to the type of grain; part may be attributed to differences in dry matter intake.

Among methods of processing, organic matter intake was 128 g less ($P<.03$; SE=50.38) with the 35C than the RC diet and 112 g less ($P<.05$; SE=50.38) for the RB diet than the SRB diet. Organic matter intake of the SFW diet was 256 and 266 g greater ($P<.004$) than for the SFC and SFM diets. These differences in organic matter intake may be explained by differences in dry matter intake.

Method of processing did not affect ($P>.05$) the nitrogen intakes. But among types of grains, nitrogen intake was greater ($P<.03$) with RW than with the RC, RM, RO, or RB diets. Rolled barley diets provided greater nitrogen intake ($P<.03$) than RC and RM diets, and nitrogen intake for the RO diet was 14 g greater ($P<.05$; SE=6.61) than for the RC diet. Though an excellent source in digestible energy, corn is low in protein, and the proteins present are poor

quality (McDonald et al., 1981). Steam flaked wheat provided greater (P<.006; SE=9.35) nitrogen intake than SFC or SFM. These differences are due to inherent differences in protein content between these grains.

Starch intakes were affected by both the method of processing and type of grain. Rolled corn, WSC, and SFC diets provided more starch (P<.05) than the 25C diet. Starch intake from the RC diet and SFW diets was greater (P<.05) than from the 35C and RW diets, respectively. Comparing the grains, WSC provided 1347 more g starch than did WO (P<.001; SE=219.23). Rolled corn had more (P<.02; SE=155.02) starch than RW, RO, or RB. Corn, at about 650 g starch/kg, is very low in fiber and high in metabolizable energy (McDonald et al., 1981). Rolled wheat, milo, and barley had more starch (P<.01; SE=219.23) than RO. The lower starch content of the ensiled grains might be due to microbial degradation during fermentation. Differences among the grain types were as expected.

Acid detergent fiber intake with RC and 35C diets was greater (P<.05) than for WSC; this probably is due to sampling error. Comparing the grains, the WO diet provided 789 g more (P<.0001; SE=66.8) fiber daily than the WSC diet. Rolled corn and wheat both presented less (P<.03) acid detergent fiber than RM and RO. Rolled oats provided more fiber (P<.001; SE=66.81) than RM and RB. Greater acid detergent fiber intake with oats is due to higher ADF of the grain. Crude fiber content of harvested grain is high-

est in oats or rice which contain a husk or hull formed from the inner and outer paleae, and is lowest in the "naked" grains, wheat and corn (McDonald et al., 1981). The nutritive value of oats depends to a large extent on the proportion of kernel (groat to hull). Oats of a high hull content are richer in crude fiber and have a lower metabolizable energy value than low-hulled oats.

Percentage dry matter of samples of rumen fluid (Table 4) varied with the method of grain processing. Rumen fluid from steers fed WSC contained 7.5 and 16.6% more dry matter ($P<.03$) than fluid from steers fed RC or SFC (SE=2.98 and 5.16). Rumen contents were mixed by hand prior to sampling, and a considerable quantity of WSC was detected in and agitated from the floor of the rumen. Poppi et al. (1980) noted that larger particles tended to be retained in the rumen for a longer period of time than smaller feed particles though density, not particle size, probably was responsible for this difference (McBride et al., 1984). Differences in the size of ruminal raft were noted, but no quantitative measurements proved feasible. The ruminal rafts in steers fed RW tended to be much thicker and denser than with other grains or methods of processing. This might be due to differences in gluten content of the grain or in rumination or specific gravity. Rolling and grinding can alter specific gravity which in turn influences retention time in the rumen and exit rate from the rumen (Barrio, 1984).

Table 4. Effect of Method of Processing Upon Ruminal Measurements

	Diets											
Item	RC	WSC	SFC	25C	35C	RW	SFW	RM	SFM	RO	WO	RB	SRB
Ruminal dry matter, %	17.10[b]	24.70[a]	8.00[b]	16.20[ab]	17.10[ab]	7.80	13.20	16.40	13.60	16.30	16.70	12.50	14.60
Ammonia-N, mg/dl[c]	6.45[a]	5.52[a]	4.82[a]	9.91[ab]	10.91[b]	14.80[b]	9.30[a]	7.63[b]	3.58[a]	10.43	9.14	15.59[b]	11.76[a]
pH[c]	6.28	6.09	6.19	6.26	6.43	6.40	6.15	6.68	6.39	6.46	6.57	6.16	6.06
Buffering capacity, ml HCl needed to change from pH:													
7.0 to 5.0	31.70	33.10	29.60	29.70	32.30	32.50	33.30	32.20	30.40	34.60	34.80	37.40	33.60
5.0 to 3.0	39.10	41.20	37.50	44.80	42.80	33.20	46.80	35.90	40.60	37.00	36.90	47.90	50.90
7.0 to 3.0	70.80	74.30	67.10	74.50	75.10	65.70	80.10	68.10	71.00	71.60	71.70	85.30	84.50

[c] These means are the average of three sampling times per animal.

Ruminal ammonia-nitrogen concentrations were affected by the method of processing (Table 4). Steers fed 35C had greater ($P<.05$) ruminal ammonia-nitrogen concentrations than steers consuming RC, WSC, or SFC. Galyean (1975) also noted greater ruminal ammonia concentrations with ground high moisture corn than steam flaked corn, dry rolled corn, or acid treated high moisture corn diets. High ruminal ammonia levels typically reflect rapid microbial degradation of the soluble portion of the feed protein (Crawford et al., 1978). Steers ingesting rolled wheat, milo, and barley had higher ruminal ammonia concentrations ($P<.05$) than those consuming steam flaked wheat, milo, and barley. Most protein sources which are soluble in the rumen are subject to rapid microbial attack and degradation. Sharp increases in ruminal ammonia levels are detected shortly after soluble proteins are fed to ruminants. Wohlt et al. (1973) observed that feeds with major protein fractions composed primarily of prolamines and glutelins (corn, milo, wheat, and barley) have reduced solubilities of proteins when processed (means of 18% vs 25%).

Comparing the grains processed similarly (Table 5), ruminal ammonia was lower ($P<.04$; $SE=1.71$) for steers fed RC than those fed RW, RO, or RB diets. Wohlt et al. (1973) reported that soluble nitrogen content of corn was low. Waldo and Goering (1979) reported mean nitrogen solubilities of 44.1, 24.8, and 17.3% for oats, barley, and corn grain measured by four methods (autoclaved rumen fluid, hot

Table 5. Effect of Type of Grain Upon Ruminal Measurements

Item	Diets									
	WSC	WO	RC	RW	RM	RO	RB	SFW	SFM	SFC
Ruminal dry matter, %	24.70	16.70	17.10	7.80	16.40	16.30	12.50	13.20	13.60	8.00
Ammonia-N, mg/dl[d]	5.52	9.14	6.45[a]	14.80[c]	7.63[ab]	10.43[bc]	15.59[c]	9.30[b]	3.58[a]	4.82[ab]
pH[a]	6.09[a]	6.57[b]	6.28[a]	6.40[ab]	6.68[b]	6.46[ab]	6.16[a]	6.15	6.39	6.19
Buffering capacity, ml HCl needed to change from pH:										
7.0 to 5.0	33.10	34.80	31.70[a]	32.50[ab]	32.20[ab]	34.60[ab]	37.40[b]	33.30	30.40	29.60
5.0 to 3.0	41.20	36.90	39.10[a]	33.20[ab]	35.90[ab]	37.00[ab]	47.90[b]	46.80	40.60	37.50
7.0 to 3.0	74.30	71.70	70.80[a]	65.70[ab]	68.10[ab]	71.60[ab]	85.30[b]	80.10	71.00	67.10

[d]These means are the average of three sampling times per animal.

water, Burroughs' solution, and sodium chloride). Steers fed RW and RB had greater ruminal ammonia concentrations than when consuming RM ($P<.02$; SE=2.43). Ruminal ammonia concentrations with the SFW diet were 5.7 mg/dl greater ($P<.04$; SE=2.43) than with the SFM diet. Miller et al. (1986) reported lower ruminal ammonia concentrations with milo, suggesting that sorghum protein resisted microbial degradation, possibly due to the tannins present. Higher rumen ammonia levels generally are ascribed to rapid microbial degradation of the soluble portion of the feed protein (Crawford et al., 1978).

Ruminal pH was not affected by the method of processing. Other researchers (Hinman and Johnson, 1974; Galyean, 1975; Cole et al., 1976c; and Sharp et al., 1982) previously have detected no significant effect of grain processing upon ruminal pH. In contrast, Britton and Stock (1986) noted that grain processing and the type and amount of grain influence ruminal pH and subacute acidosis. They indicated that wheat and barley had the fastest rates of starch digestion, whereas, whole shelled corn and dry rolled milo are generally the slowest. Steam flaked grain and rolled and high moisture corn were intermediate. Grains or methods of processing with the fastest rates of starch digestion generally created the lowest ruminal pH levels. Among grains, however, differences were detected. Steers fed WO had a ruminal pH .48 greater ($P<.04$; SE=.20) than steers fed WSC. Steers fed RM had .40 and .52 units

greater ruminal pH than when fed RC or RB, respectively (P<.02 and .03; SE=.14 and .20). Hibberd et al. (1985) attributed the high pH stability of sorghum diets to the low rate of protein and starch digestion of the milo grain. Differences in pH due to diet were smaller than expected in our trial (6.06 vs 6.68). The moderate level (1.5% body weight) of feed intake probably prevented large drops in ruminal pH.

Buffering capacity in the rumen is a function of buffering compounds such as phosphates, proteins, and volatile fatty acids (Counette et al., 1979). With increased levels of certain compounds, buffering capacity will increase. Buffering capacity was not significantly altered by the method of grain processing. Hinman and Johnson (1974), Cole et al. (1976c), and Sharp et al. (1982) detected no significant differences in total volatile fatty acids when the method of grain processing was varied. When Goetsch and Owens (1984) compared rolled milo diets with either 7% cottonseed hulls or 14 or 21% whole shelled corn, whole shelled corn appeared to have about one-third the value for ruminal pH and buffering capacity, presumably due to differences in salivary flow, ruminal mixing, and/or rumination. Among types of grain in our trial, steers fed RC had less (P<.02; SE=2.10) buffering capacity than when fed RB.

Two components of disappearance from dacron bags were separated - rate of disappearance, being represented as the

slope over time, and the initial insoluble residue which is the antilog of the intercept of this regression line. The intercept presumably includes feed components rapidly lost from the bag by either sifting through the 50 to 70 micron pores or solubilization in ruminal fluid. Differences in lag time for fermentation to begin also would cause the intercept to change. Particle filtration loss should be a characteristic of the grain, solubilization should be a function of pH and osmolarity of ruminal contents, whereas, lag time and disappearance rate are dependent on species and numbers of fermenting microbes in ruminal contents.

Both dry matter and nitrogen disappearance were analyzed for the potential interaction of grain fed x grain in the nylon bag. An interaction (Tables 6 and 7) for the initial dry matter available (antilog of the intercept) occurred in latin squares one ($P<.001$) and six ($P<.003$). There also was a significant interaction ($P<.002$) for the rate of dry matter disappearance in latin square six (Table 8). Thus, three of twenty-four measured interactions were detected as being significant.

In latin square one (Table 6) the initial washout of dry matter in RC tended to be lowest when steers were fed RW, and approximately the same when fed either rolled or steam flaked corn. The initial washout of SFC was greatest when RW was fed, followed by SFC and RC, respectively. Washout of RW was lowest when SFC was fed and similar in washout when RC and RW were fed. The mean ruminal pH val-

Table 6. Least Squares Means for Initial Washout of Dry Matter in Latin Square One

	Grain in the bag			
Diet fed	RC	SFC	RW	Average across grain in the bag
RC	23.2 (32.6)[a]	42.2 (47.2)	71.2 (57.7)	45.5
SFC	26.9 (33.9)	49.4 (48.4)	67.6 (58.9)	48.0
RW	9.0 (32.3)	54.7 (46.8)	70.8 (57.3)	44.8
Average across grain fed	19.7	48.8	69.8	2.62=SE

[a]Numbers in parentheses refer to expected values.

Table 7. Least Squares Means for Initial Washout of Dry Matter in Latin Square Six

	Grain in the bag			
Diet fed	RC	RO	WO	Average across grain in the bag
RC	20.1 (28.9)[a]	57.9 (48.9)	59.6 (52.3)	45.8
RO	12.6 (24.4)	40.1 (44.4)	57.6 (47.8)	36.8
WO	3.4 (26.1)	57.9 (46.1)	59.1 (49.4)	40.1
Average across grain fed	12.0	52.0	58.7	5.32=SE

[a]Numbers in parentheses refer to expected values.

ues were 6.40, 6.28, and 6.19 for the RW, RC, and SFC diets.

In latin square six (Table 8), dry matter digestion of RC tended to be greatest when WO was fed, followed by RO and RC in that order. Rolled oats demonstrated the greatest dry matter digestion when RO was fed and similar rates when WO or RC were fed. When RO, WO, and RC diets were fed, dry matter digestion rates of WO were greatest for the RO diets and similar for the WO and RC diets. Ruminal pH values for the WO, RO, and RC diets were 6.57, 6.46, and 6.28.

Wohlt et al. (1973) noted that as pH increased from 5.5 to 7.5, mean solubility of most high protein feeds increased from a mean of 27 to 57% of total protein. Most of the differences in solubility occurred between pH 5.5 and 6.5. Isaacs and Owens (1972) observed a similar pH effect with various protein sources and suggested that ruminal pH may affect ruminal degradation of dietary protein. Solubility should have its greatest impact on in situ disappearance during the first few hours of incubation. Effects of ruminal pH on rate of substrate disappearance after rapidly solubilized materials are removed are not well defined. Additional factors involved could include effects of protein solubilization on subsequent protein disappearance and the effect of pH on microbial degradation capacity (Barrio, 1984).

Table 8. Least Squares Means for Rate of Dry Matter Disappearance in Latin Square Six

	Grain in the bag			
Diet fed	RC	RO	WO	Average across grain in the bag
RC	2.64 (2.66)[a]	.65 (1.66)	.78 (1.11)	1.36
RO	4.10 (3.57)	4.48 (2.57)	.95 (2.02)	3.18
WO	5.15 (3.10)	.73 (2.1)	.83 (1.55)	2.24
Average across grain fed	3.96	1.96	.85	1.16=SE

[a]Numbers in parentheses refer to expected values.

Reports on potential ration x grain in the bag interactions have been contradictory. Figroid et al. (1972) stated that although differences in dry matter disappearance were observed among both rations and steers, differences in results between grains and grain processing methods due to ration were unimportant because the relative ranking of all treatments remained similar across both steers and rations. Barrio (1984) reported that diet had no influence on the disappearance of higher energy feeds, while Loerch et al. (1983) concluded the diet fed to fistulated animals for in situ experiments is important for high protein supplements. The later authors noted that nitrogen disappearance of casein, soybean meal, and dehydrated alfalfa tended to be affected more by ruminal pH than did nitrogen disappearances of blood meal, meat and bone meal, and corn gluten meal. He attributed these decreases in degradation primarily to decreases in rumen pH, probably decreasing the proteolytic bacterial species and/or ruminal protein solubilities.

Results from our trial and those of Loerch et al. (1983) suggest a possible interaction between ruminal pH and in situ digestibilities. Disappearance of certain feedstuffs are more subject to changes in the ruminal environment than are others. Such interactions may become important when drawing inferences about ruminal digestion and metabolism.

Unlike dry matter, no interactions of grain fed x grain in the bag were significant for the rate of nitrogen digestion or initial nitrogen available (antilog of the intercept) among the twelve measurements of interactions. However, the coefficients of variation were approximately four times larger and may have masked some potential differences.

Because of the grain fed x grain in the nylon bag interaction, all in situ digestion rates and initial availabilities of the dry matter and nitrogen for digestion will be compared when RC was the diet consumed. One pool, bound or unavailable protein that is degraded very slowly, was not included in the model. NRC (1985) considers the fractional degradation rate of this pool to be zero, and this protein is considered to be entirely passed. Rate of dry matter disappearance (Table 9) was 1.85% faster for 35C than for RC ($P<.05$; SE=.89). Baron et al. (1986) showed that as moisture in corn grain increased (22 to 36%), rates and extents of fermentation and proteolysis increased in both ground and whole corn grain. Galyean (1977) noted that reducing particle size increased nylon bag dry matter disappearance of unprocessed corn and milo, but processing by steam flaking or high moisture methods resulted in an additional effect on dry matter disappearance and starch digestion above that attributable from particle size alone. In his study, dry matter disappearance was greater within each particle size and time for high moisture than dry

Table 9. Effect of Method of Processing on Rate of In Situ Dry Matter and Nitrogen Disappearance

Item	Diets											
	RC	WSC	SFC	25C	35C	RW	SFW	RM	SFM	RO	WO	RB	SRB
Dry matter disappearance rate (4-24 h), %/h	-2.93[a]	-3.08[ab]	-4.56[ab]	-3.80[ab]	-4.78[b]	-3.01	-3.97	-1.73	-3.46	-.95	-1.07	-3.74	-4.35
initial washout, %	21.60[b]	20.90[b]	40.60[a]	39.20[a]	35.20[a]	69.60[a]	50.30[b]	16.60[b]	40.20[a]	59.40	61.10	56.90[a]	42.90[b]
Nitrogen disappearance rate (4-24 h), %/h	-2.16	-2.11	-2.29	-2.85	-7.12	-3.57	-4.07	-.71	-.47	+.16[a]	-6.91[b]	-2.50	-4.27
initial washout, %	17.20	13.40	-3.50	33.50	32.50	58.50	24.00	13.60	5.00	78.40	68.30	50.00[a]	10.20[b]
Bacterial nitrogen (expressed as a percent of total nitrogen of the residua)													
12 hours	1.70	0.00	0.00	.12	.62	2.15	.72	0.00	.15	4.32	3.42	4.33	3.87
24 hours	1.63	4.20	1.50	1.74	4.78	4.71	2.31	1.73	.95	0.00	0.00	.78	1.00
Dry matter disappearance, %													
4 hour	29.90	31.54	48.19	51.96	51.99	73.80	57.77	21.36	43.63	58.27	60.09	57.47	46.32
12 hour	45.15	49.12	70.39	58.77	59.67	80.48	72.80	34.99	65.10	62.11	64.22	73.45	66.86
24 hour	60.54	63.78	79.76	76.10	80.41	85.54	81.94	52.58	76.57	63.59	66.04	77.95	75.23
Dry matter disappearance rate, %/h													
4-12 hour	-3.13[a]	-3.76[ab]	-6.05[b]	-3.82[ab]	-3.78[ab]	-2.74	-5.62	-1.11[a]	-4.72[b]	-1.70	-1.85	-6.65	-6.77
12-24 hour	-2.82	-2.68	-3.70	-3.79	-5.37	-3.16	-3.01	-2.09	-2.73	-.51	-.61	-2.04	-2.94

Table 9. (Continued)

Item	Diets												
	RC	WSC	SFC	25C	35C	RW	SFW	RM	SFM	RO	WO	RB	SRB
Nitrogen disappearance, %													
4 hour	26.52	22.17	14.91	42.66	53.83	70.01	38.73	18.09	11.15	77.94	75.85	48.46	15.78
12 hour	35.28	28.52	27.99	48.65	63.63	83.45	49.85	16.29	1.54	85.97	90.89	72.88	52.10
24 hour	49.76	46.10	43.02	67.48	91.45	84.98	70.77	17.09	5.54	83.78	89.47	62.67	54.02
Nitrogen disappearance rate, %/h													
4-12 hour	-1.64	-2.45	-1.38	-1.78	-2.36	-7.57	-3.93	-1.12	+.01	+1.46	-10.59	-6.89	-6.25
12-24 hour	-2.47	-1.92	-2.83	-.45	-8.43	-1.23	-4.16	-.48	-.75	-.59	-4.77	+.06	-3.11

ground corn. He conjectured that solubilization of the protein matrix surrounding the starch granule made the starch more accessible to amylolytic bacteria. Nocek (1978) suggested that moisture content or microbial fermentation associated with storage could enhance ruminal degradation of high moisture corn and this might be attributed to a greater degree of amorphism of the starch granules, which hasten solubilization and microbial infiltration. Less rapid in situ disappearance with the dry corn forms may be associated with increased integrity and crystallinity of the hard endosperm fraction of the grain which reduced its accessibility for solubilization and digestion. Rate of dry matter digestion tended to match extent of ruminal starch digestion in Chapter III. While not significantly different (P>.05), ruminal starch digestion was 2% greater with 35C than RC (86.4% vs 84.4%). Across all grains and processing methods, rate of dry matter disappearance in this trial and apparent dry matter digestion in Chapter III were negatively related (r=-.74; P<.004).

Rate of dry matter disappearance through 24 hours (Table 10) was 1.99% and 2.79%/h faster with RC and RB than with RO (P<.03; SE=.89 and 1.27). Barrio (1984) also observed a faster rate of dry matter disappearance (8.21 vs 1.19%) with rolled corn than with rolled oats. Lower starch and higher fiber content may be responsible.

Initial washout varied with the method of processing and the type of grain. Steam flaked corn, 25C, and 35C had

Table 10. Effect of Type of Grain on Rate of In Situ Dry Matter and Nitrogen Disappearance

Item	Diets									
	WSC	WO	RC	RW	RM	RO	RB	SFW	SFM	SFC
Dry matter disappearance rate (4-24 h), %/h	-3.08	-1.07	-2.93[b]	-3.01[ab]	-1.73[ab]	-.95[a]	-3.74[b]	-3.97	-3.46	-4.56
initial washout, %	20.90[b]	61.10[a]	21.60[b]	69.60[a]	16.60[b]	59.40[a]	56.90[a]	50.30	40.20	40.60
Nitrogen disappearance rate (4-24 h), %/h	-2.11	-6.91	-2.16	-3.57	-.71	+.16	-2.50	-4.07	-.47	-2.29
initial washout, %	13.40[a]	68.30[b]	17.20[a]	58.50[bc]	13.60[ab]	78.40[c]	50.00[abc]	24.00	5.00	-3.50
Bacterial nitrogen (expressed as a percent of total nitrogen of the residue)										
12 hours	0.00	3.42	1.70	2.15	0.00	4.32	4.33	.72	.15	0.00
24 hours	4.20	0.00	1.63	4.71	1.73	0.00	.78	2.31	.95	1.50
Dry matter disappearance, %										
4 hour	31.54	60.09	29.90	73.80	21.36	58.27	57.47	57.77	43.63	48.19
12 hour	49.12	64.22	45.15	80.48	34.99	62.11	73.45	72.80	65.10	70.39
24 hour	63.78	66.04	60.54	85.54	52.58	63.59	77.95	81.94	76.57	79.76
Dry matter disappearance rate %/h										
4-12 hour	-3.76	-1.85	-3.13[a]	-2.74[a]	-1.11[a]	-1.70[a]	-6.65[b]	-5.62	-4.72	-6.05
12-24 hour	-2.68	-.61	-2.82	-3.16	-2.09	-.51	-2.04	-3.01	-2.73	-3.70

Table 10. (Continued)

Item	Diets									
	WSC	WO	RC	RW	RM	RO	RB	SFW	SFM	SFC
Nitrogen disappearance, %										
4 hour	22.17	75.85	26.52	70.01	18.09	77.94	48.46	38.73	11.15	14.91
12 hour	28.52	90.89	35.28	83.45	16.29	85.97	72.88	49.85	1.54	27.99
24 hour	46.10	89.47	49.76	84.98	17.09	83.78	62.67	70.77	5.54	43.02
Nitrogen disappearance rate %/h										
4-12 hour	-2.45	-10.59	-1.64	-7.57	-1.12	+1.46	-6.89	-3.93	+.01	-1.38
12-24 hour	-1.92	-4.77	-2.47	-1.23	-.48	-.59	+.06	-4.16	-.75	-2.83

greater (P<.008, SE=5.02; P<.05, SE=7.10) quantities of soluble dry matter washout than RC or WSC. Galyean (1977) observed greater (11.8 and 22.1 vs 7.0%) soluble dry matter washout for steam flaked and high moisture corn than for dry ground corn.

Steam flaking and steam rolling decreased the immediate in situ losses of dry matter from wheat (P<.008) and barley (P<.007) but increased the initial washout of dry matter in milo (P<.0001) compared with the rolled forms of these grains. Frigoid et al. (1972) reported disappearance rate of sorghum dry matter (4.5 vs 2.6%) was increased by steam processing and flat flaking as compared to dry rolling but initial disappearance of dry matter was reduced (66.6% vs 95.4%). They also indicated that the dry matter disappearance extents of dry rolled and steam processed flat flaked barley were similar. One of the most common methods of protecting dietary proteins from ruminal degradation to increase the proportion reaching the small intestine involves heat. Controlled heat can reduce the soluble fraction of dietary proteins (Crooker et al., 1986) probably by binding protein to fibrous components.

Whole oats had 40.2% more initial washout of dry matter than WSC (P<.0001; SE=7.10). Both RC and RM had less (P<.0001) initial washout of dry matter than RO, RB, or RW. Thomas et al. (1987) suggested that wheat starch is more available to ruminal microorganisms because its starch

structure is less dense and higher in amylose and reducing sugar content than corn or milo.

Rate of nitrogen digestion was not affected by the type of grain but was 7.07% faster with WO than RO ($P<.05$; SE=3.53). No explanation for this is apparent; it may be an artifact. Standard error for the nitrogen digestion rates of WO and RO was 3.38. Nocek (1987) detected no differences in nitrogen digestion of corn processed by several methods.

Initial nitrogen available for in situ digestion was 39.9% greater for SRB than RB ($P<.03$; SE=17.59). Across all the grains, heat treatment tended to decrease protein solubility, probably due to alteration or denaturation of the protein. Initial nitrogen available in SFC was 103.50%. Because this is physically impossible, this value presumably reflects a lag time in digestion or an accelerating digestion rate.

Britton and Stock (1986), indicating that diet composition impacts upon subacute acidosis and feed intake, categorized grains by the rate of breakdown in the rumen. Dry matter disappearance rates between 12 and 24 hours were similar ($P>.05$) between the various grains and methods of processing. When the methods of processing were compared, rate of dry matter disappearance between 4 and 12 hours was 2.92% and 3.16% faster ($P<.01$ and .002; SE=1.11) for steam flaked than rolled corn and milo. Among the grains, RB had a faster rate ($P<.02$) of dry matter disappearance between 4

and 12 hours than any of the other rolled grains. Hence, dry matter disappearance from 4 to 12 hours may be useful as a potential index for acidosis.

Whole shelled corn had 54.9% more nitrogen available initially than WO ($P<.03$; SE=24.88). Similarly, RC had 41.4% and 61.2% greater in situ nitrogen than RW and RO ($P<.03$, SE=17.59). Crawford et al. (1978) reported nitrogen solubilities of 11.3, 35.1, and 45.7% for corn, wheat, and oats. MacGregor (1978) also reported decreased protein solubilities (15 vs 31%) for oat versus corn grain. Differences with our results suggest that washout of dry matter was responsible primarily for initial loss of N with oats. Washout of dry matter was positively related with nitrogen disappearance at four hours ($r=.73$; $P<.005$). In our trial, RM had 64.8% greater nitrogen available than RO ($P<.02$; SE=24.88); this probably is due to differences in solubilities and the tannin content of the milo.

Across all methods of processing (Figure 1), rate of nitrogen and dry matter disappearance were weakly related ($r=.27$; $P<.36$); whereas, initial washout of dry matter and nitrogen (Figure 2) were strongly related ($r=72$; $P<.006$). The initial loss of dry matter is presumably due to particles selective for protein. Adjusted ruminal nitrogen digestion from Chapter III was positively related in this trial with initial washout of dry matter and nitrogen, respectively ($r=.71$ and .63; $P<.007$ and .03).

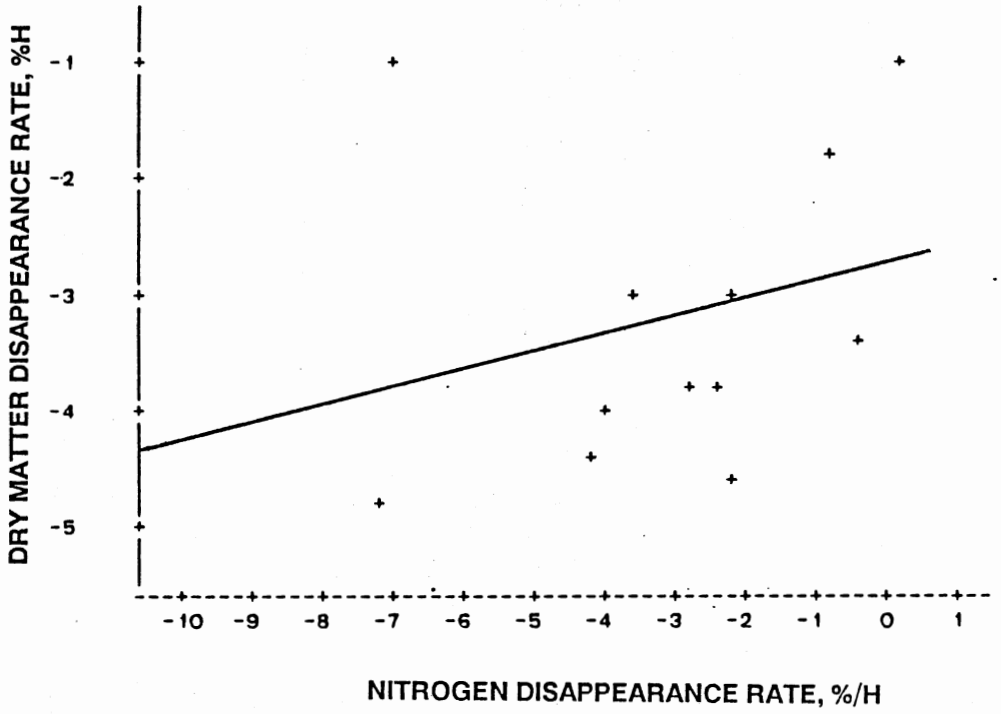

Figure 1. Nitrogen Disappearance Rate vs Dry Matter Disappearance Rate

+ = -2.724 + .155 (nitrogen disappearance rate); r=.27; P<.36

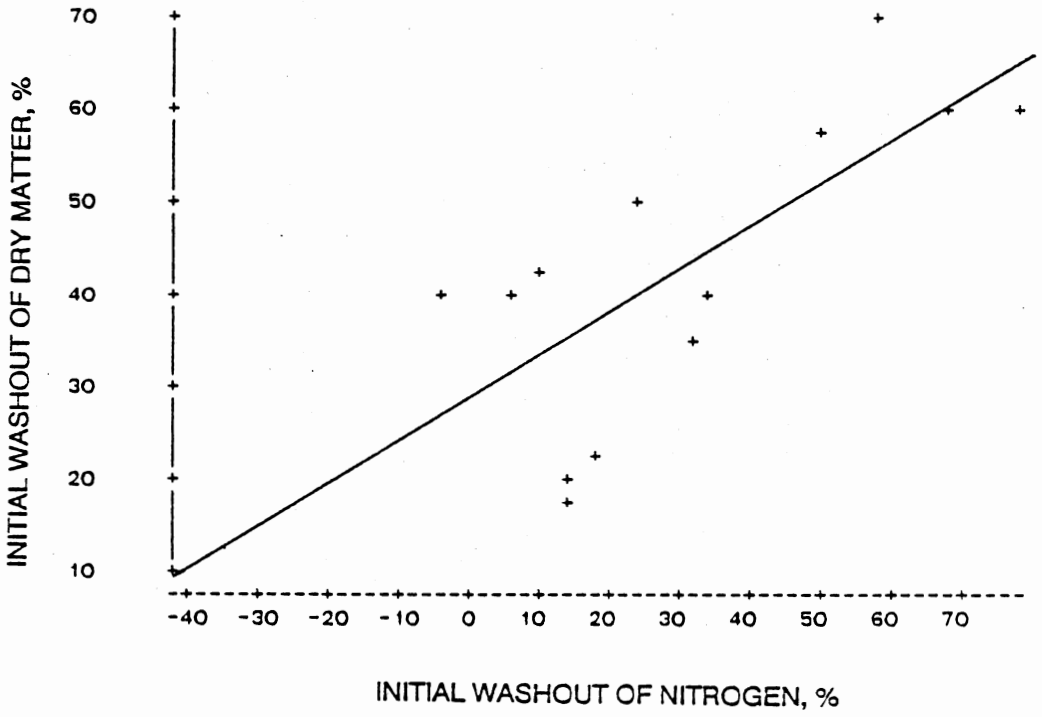

Figure 2. Initial Washout of Nitrogen vs Initial Washout of Dry Matter

+ = 28.321 + .465 (initial washout of nitrogen); r=.72; P<.006

Electron microscopy studies have shown that rumen bacteria colonize and adhere to plant particles during fermentation (Mather and Aitchison, 1981). The diet fed to the animal during the sample collection will influence the extent of microbial nitrogen enrichment of the feed particles enclosed in the nylon bag. Such microbial attachment to the feed residues may be an important source of error in the study of quantitative feed-protein degradation and, to a lesser extent, feed dry matter degradation (Varvikko and Lindberg, 1985; Olubobokun et al., 1987). The resulting contamination of feed residues by microbial matter will lead to the greatest underestimation of protein degradability where feeds have low protein content and high disappearance. Attachment would be expected to be higher for forages than grains due to inherent spaces for attachment. Also, values estimated from DAP may overestimate total microbial N present due to the prevalence of attached microbial cell walls (ghosts) as discussed by Demeyer et al. (1980).

Results from Tables 9 and 10 show that residues remaining after 12 or 24 hours in situ digestion were only slightly enriched in nucleic acid content. Percentages of residual nitrogen which presumably were of microbial origin ranged from zero to maximums of 4.33% and 4.78% for bags removed at 12 and 24 hours, respectively. Weakley (1983) suggested that microbial contamination of extracted soybean meal may be as high as 6% of the residual feed nitrogen.

Mathers and Aitchison (1981) reported microbial contamination of fish meal after 24 hours exposure in situ was less than 2% of the residual nitrogen; in contrast it comprised 20% of residual N with alfalfa. From 2.3 to 7.6% of residual soybean nitrogen may be bacterial nitrogen according to Crooker et al. (1986). Extent of washing of the bags and feed residues following in situ digestion certainly will affect the degree of contamination with bacteria. The amount of hair from animals grooming themselves which becomes entrapped in the bags also will cause purine nitrogen concentrations to be overestimated. Higher values for forage contamination might be expected though values exceeding 95% (Olubobokun et al., 1987) are not realistic and might be ascribed to enrichment by tightly attached bacterial ghosts with their inherent DAP.

In conclusion, potential interactions (grain fed x grain in the nylon bag) may alter dry matter disappearance from grains. This grain fed x grain in the bag effect occurred with RW x RC (9% actual vs 32.3% expected dry matter washout), WO x RC (3.4% actual vs 26.1% expected dry matter washout), and WO x RC (5.15% actual vs 3.10% expected rate of dry matter disappearance). Effects appeared to be detected only at higher ruminal pH levels. Various methods of processing and types of grain greatly altered in situ disappearance of dry matter and nitrogen. Further research is needed to assess the effects of ruminal passage rate and

level of feed intake upon the digestion of dry matter and nitrogen.

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APPENDIXES

APPENDIX A

THIAMIN DEFICIENCY IN FEEDLOT CATTLE: A CASE STUDY

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Summary

This paper presents the case history of one research animal, a 700 pound black baldy steer, and its encounter with the thiamin deficiency condition, cerebrocortical necrosis. After receiving 82% concentrate diets for 38 days, this steer began to exhibit muscular incoordination, opisthotonus, head pressing, blindness, and convulsions. Blood thiamin analyzed below .5 ppm, the lower limit of the analytical procedure. Treatment included 6 ml of thiamin hydrochloride immediately and 7 ml daily for three consecutive days. The steer regained his coordination and appetite but remained visually impaired. Subsequent to this condition, he was supplemented daily with 200 mg thiamin hydrochloride.

(Key Words: Thiamin, Feedlot Steers, Cerebrocortical Necrosis, Grain)

Introduction

Thiamin is an obligatory requirement in energy metabolism at the tissue level. In ruminants a large part of the thiamin supply can be met from microbial synthesis in the rumen. Hence, B vitamin deficiencies occur only rarely. Cerebrocortical necrosis (CCN) [or polioencephalomalacia] is a particular form of thiamin deficiency due either to reduction in the supply of thiamin from the rumen or to production of an antibody to thiamin. The presence of a naturally occurring second substrate (co-substrate) could produce, by the thiaminase I reaction, a potent thiamin anti-metabolite which accentuates the condition (Roberts and Boyd, 1974).

Thiamin status varies according to the thiamin intake, thiamin synthesis, the presence of thiaminase in the rumen, and the effects of possible antimetabolites. Reported outbreaks of the disease often have been associated with sudden changes in diet and management, but the precise cause has not been determined (Nyack et al., 1983). It can be assumed that intensively fed animals would require large amounts of thiamin but daily thiamin outflow from the rumen should be 13.9 to 24.4 mg (Miller et al., 1986 and Zinn et al., 1987). CCN may be of increasing importance under conditions of intensive feeding for higher rates of weight gain. Surveys on farms and fattening units suggest that at least 25% of the younger cattle may be regarded as being in

a thiamin-deficient state (Edwin and Jackman, 1982). The case history of one of our research animals, a 700 pound black baldy steer, and his encounter with CCN is described in this paper.

Materials and Methods

This steer, a native-bred animal, was purchased in the spring of 1986 at the Oklahoma City Stockyards. Prior to purchase, the steer had grazed wheat pasture with 3 to 4 pounds of a corn-oat supplement daily. One week after arrival in Stillwater, he received IBR, PI_3, Lepto, Haemophilus and BVD vaccinations, a vitamin A and D injection and Ivermectin for deworming. Approximately one month later, this animal was surgically equipped under anesthetic by veterinary surgeons with a 4 inch internal diameter rumen cannula. This steer was used in experiments starting one month later. The steer was maintained on a prairie hay diet and received about 2 pounds of a 40% protein supplement for this two-month period. During the experiments, the steer was fed a high grain ration (Table 1) and was in a 3x3 m pen with free access to water.

One month was used to adapt the steer to the high grain diet. Once adapted, the animal received steam flaked corn, rolled wheat, rolled corn, and steam flaked wheat diets for 10-day periods. The diet was 82% grain, 12% cottonseed hulls, 2% molasses, 1.3% limestone, 1% urea, .6% KCl, .5% salt, .5% sodium sulfate, vitamin A, monensin at

Table 1. Composition of Finishing Ration (dry matter basis)

Ingredient	%	
Grain[a]	77.22	
Cottonseed hulls	12.00	
Molasses	2.00	
Chromic oxide	.30	
Pelleted supplement	8.48	
Calcium carbonate		1.29
Dicalcium phosphate		.24
Vitamin A-30		.01
Potassium chloride		.61
Trace mineral salt		.50
Sodium sulfate (Na_2SO_4)		.50
Urea		1.00
Rumensin 60		.02
Tylan 40		.04
Number 2 dent corn		4.27

[a] The grain fed each period was altered so that steam flaked corn, rolled wheat, rolled corn, and steam flaked wheat were consumed.

30 g/ton and Tylan. Feed intake was limited to 1.5% of body weight daily (dry matter basis).

On the eighth day on the steam flaked wheat ration, day 38 on trial, the steer began to refuse feed. Sampling was cancelled, and rolled corn was substituted for wheat in the diet to reduce ruminal fermentation rate and speed recovery. However, feed refusals increased. To aid rumen function, three gallons of rumen fluid from another steer consuming the rolled corn ration was transferred into the rumen of the steer via cannula. Two days later, 5 days after initial feed rejection, the steer developed diarrhea. Rectal temperature was normal. One-half gallon of kaopectin was dosed into the rumen, and 20 ml of Albon (sulfadimethoxine; produced by Hoffmann LaRoche, Inc., Nutley, NJ) was administered into the jugular vein. Three gallons of rumen fluid from a second donor steer fed the rolled corn diet and 3 gallons from a third steer fed the steam flaked wheat diet also were transferred into the rumen of the sick steer.

When trying to halter and treat the steer the next morning, 6 days after initial feed rejection, the steer fell on his side with his legs in an extended position. Veterinary examination revealed a normal temperature, rigidity of the limbs, diarrhea and loss of vision. Blood was drawn via the jugular for analysis, and drug therapy was given. Thiamin concentration in the blood was checked by Hoffmann LaRoche, Inc., Nutley, NJ. Blood thiamin was

below .5 ppm, the lower detection limit of the analytical procedure. Six ml of thiamin hydrochloride (3 ml IV, 3 ml IM) and 40 ml of penicillin (IM) were administered. Thirty minutes later, the steer went into shock rolling his head over his back, rotating his eyes and twitching his ears.

The symptoms persisted for the next 24 hours. Suspected diagnoses included lead poisoning, rabies, Haemophilus and thiamin deficiency. Blood levels of lead were normal (4 ppm). Feces were checked for coccidiosis and revealed very few eggs. Each of the next three days, 7 ml thiamin hydrochloride (IM), 3 sulfa pills and 40 ml penicillin (IM) were given. Thiamin injections produced reactions indicative of a burning sensation. The steer regained his coordination and appetite but remains visually impaired. He has been placed on high grain diets, but subsequent to this condition diets for all steers on trial have been supplemented daily with 200 mg thiamin hydrochloride.

Results and Discussion

The pathology of CCN includes a characteristic softening and degeneration of the brain gray matter which leads to circling, muscular incoordination, opisthotonus (drawing the head back over the shoulder) and head pressing, progressing to blindness, convulsions and death. Only a few animals develop CCN; if treated early, they respond to

large intravenous doses of thiamin. If treatment is delayed, survivors may be permanently blind or may suffer permanent central nervous system impairment (Brent, 1985).

Precise thiamin requirements are unknown for ruminants. Extrapolation of requirements for monogastrics would predict that the thiamin present in common feedstuffs should exceed the need by 3 to 4 times. Ruminal escape of dietary thiamin is suggested to be about 52 percent; whereas, ruminal synthesis is about 8 mg per kg digestible organic matter consumed (Zinn et al., 1987). However, in 20 kg of rumen contents, thiaminase activity can account for the destruction of up to 20 mg of thiamin per minute (Edwin and Jackman, 1982).

The thiaminase I hypothesis can be stated as follows: in the rumen, thiaminase I, in the presence of a suitable cosubstrate, not only destroys thiamin, but creates a thiamin analog that inhibits one or more thiamin-requiring reactions necessary for energy metabolism in the central nervous system (Brent and Bartley, 1984). Thiaminase activity is present not only in the rumen contents and feces of animals with CCN, but also is often found in clinically normal animals. Because thiaminase I is everpresent in the rumen, the rate of the thiaminase I reactions probably depends on the rumen cosubstrate concentration (Brent, 1985). The preferred cosubstrate for thiaminase I from spontaneous CCN cases was aniline. Niacin had 23 to 45% and pyridoxine, 23 to 41% the activity of aniline. Histamine and imidazole

were only slightly less active than niacin (Brent and Bartley, 1984). The fact that niacin is a cosubstrate suggests that thiaminase could cause depletion of both these vitamins (Roberts and Boyd, 1974). Using levels of ruminal thiaminase commonly found in apparently healthy young calves, the calculated capacity for thiamin destruction within the rumen is approximately 1 mg/kg of digesta (Jackman, 1985).

Under the antimetabolite hypothesis, CCN might be caused by one or several specific antimetabolites. It is possible that a range of naturally occurring rumen amines is involved. Some of these might come from the ruminal metabolism of amino acids (Brent, 1985). Grigat and Mathison (1983) noted, however, a negative trend ($r=-.82$, $P<.10$) between the crude protein content of feedlot diets and the mean thiamin pyrophosphate effect suggesting that a relationship exists between the nitrogen content of the diet and the thiamin adequacy of the animal. Miller et al. (1986) observed greater ruminal destruction of thiamin tended to occur in steers fed a high concentrate diet (11.4% CP) than in those fed a low concentrate diet (17.3% CP).

A number of other factors have been suggested which may predispose an animal to CCN. These include cobalt deficiency, inorganic sulfate, and lactic acidosis (Jackman, 1985). Elevated sulfate from gypsum, dynamate or other sources increased ruminal thiamin destruction when sulfate

was present at .51% of the diet, well above the .34% sulfate in our ration. Goetsch and Owens (1986) reported addition of $MgKSO_4$ to the diet reduced duodenal flow of thiamin due both to reduced escape and reduced ruminal synthesis of thiamin.

Brent (1976) proposed that lactic acidosis may set the stage for spontaneous production of CCN. When highly fermentable diets are provided to ruminants, pH of the rumen decreases. This may result in proliferation of thiaminase-producing bacteria. Ruminal loss of thiamin and low pH did not appear to be related in a recent trial by Miller et al. (1986) but ruminal pH did not vary widely among diets. The intensity of the activities and the pH optima of the thiaminases may vary with the bacterial source, so one cannot be certain that CCN will occur only in specific ruminal pH ranges (Edwin and Jackman, 1982).

B vitamin nutrition of ruminants warrants further investigation. Thiamin deficiency noted in feedlots presumably is the result of some unknown combination of factors including genetic background of the animal, type and processing of the ration, feed additives and physiological status of the steer. Prevention is more complex.

Although high levels of thiamin in the diet will lead to more circulating thiamin, if the concentration of thiaminase I and cosubstrate are not rate limiting to the thiaminase I reaction, feeding thiamin would increase thiamin analog synthesis, and could conceivably precipitate CCN

(Brent and Bartley, 1984). Other researchers (Zinn et al., 1987; Goetsch and Owens, 1986) reported that B vitamin supplementation tended to reduce morbidity and did not increase ruminal degradation of thiamin.

It is not known whether subclinical deficiencies, which could limit animal production and possibly cause health problems in feedlot cattle, are prevalent in the field (Grigat and Mathison, 1983). The largest feedlot in the Southern hemisphere adds 1 g thiamin daily to each steer's diet for 7 days whenever CCN is diagnosed and has never encountered a second case. Whether thiamin supplementation on a regular basis would prevent this problem or cause other problems and what levels might be useful (200 mg thiamin HCl costs 1.7 cents) remains to be determined.

APPENDIX B

YTTERBIUM LABELING OF GRAIN: EFFECT OF GRAIN PROCESSING, PARTICLE SIZE AND EXTRACTION METHOD

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Summary

Five types of grain (corn, wheat, milo, barley and oats) subjected to one of six processing methods [high moisture ensiling (25% and 35% dry matter), steam flaking, whole, rolling or steam rolling] were labeled with ytterbium. Ytterbium content was analyzed following either extraction by EDTA or ashing. Ytterbium concentrations determined after ashing were an average of 21% higher (5.88 vs 4.84 mg/g DM) and more repeatable (SE=.28 and .53) than after EDTA extraction. Form of grain processing and particle size affected both the amount of feed recovered after labeling and washing (whole > rolled > steam flaked) and the quantity of ytterbium bound (steam flaked and steam rolled > rolled > whole). Differences in grain recovery

and extent of labeling with ytterbium are related partially to differences in particle size.

(Key Words: Ytterbium Extraction, Grain Processing, Particle Size)

Introduction

Rare earth elements, such as ytterbium (Yb) have an affinity for plant cell walls and once attached can be used to study the rate of passage of particulate digesta in ruminants (Hart and Polan, 1984). However, the binding affinity or capacity of particulate matter for Yb varies with the type of feed indicating that (1) the functional groups that bind Yb vary with the feedstuff, (2) the molecular environment of functional groups varies with the feedstuff or (3) some types of particulate matter form multiple bonds with Yb (Teeter et al., 1984). With the immersion-washing procedure, feed composition is modified some what by the removal of soluble components.

Daily intakes of .8 g Yb per steer are recommended (Karimi et al., 1987) to achieve 2 ppm in the final fecal extract for analysis by atomic absorption. Although information concerning binding capacities of various roughages have been published (Teeter et al., 1984), values of the Yb binding capacities of grains and the percentage of grain lost during the immersion-washing procedure are lacking.

Two methods for preparation of samples for Yb analysis have been proposed. One method (Ellis et al., 1982) is

quite time consuming, involving ashing a dry sample and extraction of Yb from the ash with acid. A second method (Hart and Polan, 1984) is rapid, consisting simply of extracting Yb with an EDTA solution. These two methods also vary in the size of the sample employed, with the ash method using 1 to 2 grams of sample versus only .2 g with the EDTA extraction. The smaller the sampling size, the greater the error in representative sampling.

Yb concentrations in feed also may differ depending on the extraction method employed. Higher values have been suggested with the ashing procedure. However, Karimi et al. (1987) noted no reduction in the reliability of measurement with the EDTA extraction.

The objectives of our research were: 1) to determine the relationship between the method of grain processing and the binding capacity for Yb, 2) to investigate the effect of grain processing method on recovery of Yb-labeled product and 3) to compare results from these two methods for Yb extraction.

Materials and Methods

Five types of grain (corn, wheat, milo, barley and oats) subjected to one of six processing methods [high moisture ensiled (25% and 35% dry matter), steam flaked, whole, rolled or steam rolled] were treated with Yb to study passage rate. Grains were processed commercially from a single batch of each grain. Two and one-half grams of $YbCl_3.3H_20$

were dissolved in one liter of distilled water, poured onto 50 grams of air dry feedstuff and allowed to soak for 48 hours, during which time the mixture was stirred three to four times each day (Galyean, 1984). The grain solution then was filtered through a 250 micron screen and washed six times with distilled water over a six hour period. The labeled grain was dried at 60 C. Percentage recovery of the grain was expressed as final dried weight of the grain after the immersion-washing procedure divided by the initial as-fed weight of the grain before labeling with Yb.

The grains were characterized before immersion by dry sieving through a series of screen sizes (8mm, 4mm, 2mm, 1mm, 500 microns, 250 microns and 125 microns) to attain a particle size distribution (Table 1).

Yb was extracted from samples of each batch of labeled grain by the EDTA extraction of Hart and Polan (1984) and by ashing plus acid extraction (Ellis et al., 1982). Yb concentrations of the extracts were measured by atomic absorption spectrophotometry using a nitrous oxide flame. To determine potential differences in Yb binding, statistical analysis of the data involved a one way classification of each labeled grain with replication within grain serving as the error term. Differences between methods of processing within grain and amount of Yb bound were estimated. Linear regression was used to compare the two methods of Yb extraction.

Table 1. Particle Size Distribution of Processed Grains

Grain and form	Size of sieve openings							
	8mm	4mm	2mm	1mm	500um	250um	125um	Pan
	------ Percentage of grain remaining on screen ------							
Steam flaked corn	28.9	38.5	18.8	7.9	3.6	1.6	.2	.7
Whole shelled corn	25.8	73.4	.8	--	--	--	--	--
Rolled corn	3.2	49.4	40.6	6.0	.4	.2	.2	--
25% High moisture corn	4.6	37.4	39.9	11.3	4.8	1.1	.2	.9
35% High moisture corn	5.0	36.2	42.8	13.0	2.2	.3	--	.6
Rolled wheat	--	6.3	79.0	13.5	.8	.1	.3	.1
Steam flaked wheat	--	31.5	55.0	11.8	.9	.2	.2	.4
Rolled milo	--	--	57.6	41.7	.6	--	.1	.1
Steam flaked milo	--	9.7	43.7	30.0	10.1	4.8	.7	1.1
Rolled barley	--	30.3	67.0	2.6	.1	--	--	--
Steam rolled barley	--	40.8	58.8	.3	--	--	--	--
Rolled oats	--	16.0	77.2	4.6	1.1	.4	.4	.4
Whole oats	--	14.9	82.2	2.7	.1	--	--	--

Results and Discussion

Mean ytterbium concentrations for the 13 feeds are reported for the EDTA and ashed extraction methods (Table 2). Ytterbium concentrations were greater for 12 of the 13 feeds tested by acid extraction of ash than by the EDTA extraction method. Averaged across feeds, the ash extraction procedure proved more repeatable than the EDTA extraction method (SE=.28 and .53, respectively). Hart and Polan (1984) and Karimi et al. (1987) reported previously that extraction with a chelate (EDTA) simplified analysis of digesta samples without reducing the reliability of the measurement. In our study, the correlation between the two methods was high (r^2=.83; P<.0001) but EDTA extraction tended to under-predict the Yb concentration. This difference may be important when choosing an extraction method for samples having low Yb concentrations.

The intercept and slope of the regression between the two extraction methods were estimated to be 1.47 mg/g DM and .91, respectively (SE=.68 and .12; P<.05 and <.0001). The non-zero intercept indicates that passage rates estimated by the regression of the natural logs of the Yb concentration will not be equal. Hence, passage rates determined by the EDTA extraction method will not be the same as with the ash-acid extraction method. If the regression intercept is not zero, even though the feed/digesta extraction ratios are similar, extrapolation to zero time also will give different

Table 2. Ytterbium Concentrations of Feeds

Feed	Yb concentration (mg/g DM)			
	EDTA Extraction	SE	Ash Extraction	SE
Steam flaked corn	4.88	.66	6.16	.07
Whole shelled corn	1.20	.06	1.53	.00
Rolled corn	3.40	.07	4.52	.46
25% High moisture corn	2.23	.13	3.26	.11
35% High moisture corn	2.52	.13	3.19	.11
Rolled wheat	5.18	.51	5.72	.72
Steam flaked wheat	11.59	1.21	10.35	.02
Rolled milo	5.64	1.06	5.92	.00
Steam flaked milo	6.45	.38	7.13	.21
Rolled barley	5.93	.40	9.05	.12
Steam rolled barley	6.85	.25	9.88	.35
Rolled oats	4.51	.06	5.77	.28
Whole oats	2.60	.07	3.94	.00
Average of all feeds	4.84	.53	5.88	.28

rumen fill estimates, with the EDTA extraction method predicting smaller rumen volumes.

The dry matter content of the labeled feeds and the percentage feed recovered following immersion-washing varied among the feeds tested (Table 3). Form of processing affected the amount of feed recovered, with whole > rolled > steam flaked. This trend can be related primarily to differences in particle size. However, the type of feed and solubility of its components were important. Additional amounts of high moisture corn and rolled wheat had to be labeled because of loss of very small particles and(or) soluble components.

Particle size also affected the amount of Yb bound to the feed. Rolling of oats and corn both increased ($P<.0001$) the amount of Yb bound compared to the whole forms of either grain. Teeter et al. (1979; 1984) also reported that binding capacities were greater for rolled than for whole milo and corn. Steam flaking of corn, milo and wheat further increased ($P<.001$) Yb binding (1.65, 1.21 and 4.63 mg/g DM) as compared with rolled forms of these grains. Steam rolled barley bound more ($P<.01$) Yb/g DM than rolled barley. Hence, binding of Yb tended to be related to the method of processing with steam rolled and steam flaked > rolled > whole. Differences in the amounts of Yb bound can be related to differences in the amounts of surface exposed for Yb binding.

Table 3. Dry Matter and Percentage Feed Recovered

Feed	Dry matter of feed recovered	Percentage recovered[a]
Steam flaked corn	84.74	72.38
Whole shelled corn	90.85	97.50
Rolled corn	90.36	86.04
Rolled wheat	89.75	53.74
Steam flaked wheat	88.39	76.18
Rolled milo	97.36	83.59
Steam flaked milo	94.10	64.23
Rolled barley	95.29	72.65
Steam rolled barley	95.34	84.72
Rolled oats	96.34	80.11
Whole oats	95.84	90.13

[a]Percentage grain recovered was expressed as weight of dried grain after the immersion-washing procedure divided by the initial weight of the grain before labeling.

Solubility of feed components also may be important in the binding capacity of the grain. Rolled corn bound greater ($P<.001$) concentrations of Yb than high moisture corn. The decreased binding of Yb with high moisture corn may be due to higher solubility of the starch in the ensiled product. However, the differences in binding between the 25% and 35% high moisture corn were small ($P>.05$).

Differences in the amounts of grain recovered and labeled with Yb may be related to differences in particle size, although particle size alone cannot account for all the variability. Ellis et al. (1982) noted that feeds higher in fiber tended to have greater binding capacities. Starch, in contrast, has a low binding capacity suggesting that groups other than those presented by polyglucans are involved. Certain processing methods, such as ensiling and heat treatment, may alter the chemical and physical composition and solubility of components (e.g., starch, protein) which in turn will influence binding and recovery. Intracellular components of feedstuffs, such as protein and nucleic acids may physically bind Yb, but the opportunity for exposure would be much lower than for surface structures. Nevertheless, their exposure for binding should increase with processing.

Variations among grains and forms of grain both in extent of labeling and in recovery following immersion-washing are disconcerting. First, they indicate that labeled feed will differ from unlabeled feed in physical and possibly

chemical properties and subsequently in ruminal kinetics (e.g., ruminal distribution, wetability, flow rate). Whether the depression in digestion rates attributed previously to Yb (Teeter et al., 1984; Mader et al., 1984) is due to altered composition (removal of small particles and soluble components) or to attachment of rare earth to microbial binding sites is uncertain. Because Yb concentrations increase during in situ incubation, reduced microbial attachment is presumed. If this reflects altered wetability and density, altered passage also might be of concern. Difference in total Yb uptake with grain processing indicated that structural components presumably differ in extent of labeling. If true, and if these components differ in extent of ruminal digestion and rates of passage, comparison among grains may prove misleading. One alternative to the immersion-washing procedure would be to dose the rare earth directly into the rumen. Unfortunately, haphazard binding to small particles and solutes (e.g., VFA) drastically complicates interpretation of data obtained by ruminal dosing.

The search for the perfect marker is likely to continue. It remains uncertain whether the ideal particle to mark should be subject to the same fermentation, density and particle size changes in the rumen as untreated feedstuffs or whether, as with mordanted fiber, that the ideal particle should be inert to such changes. Marker migration certainly is reduced by mordanting. But if digestible particles are preferentially retained in the rumen, fermentability of the

particle should be retained in order to monitor and understand ruminal kinetics of dietary particles. It is unfortunate that particulate marker procedures are not checked routinely by comparing ruminal fill with duodenal flow. Despite lack of confidence in the precision of marker procedures, observed changes in passage rate due to animal, feed or feeding factors seem to be reliably and repeatedly detected. Consequently, one should be less concerned about reliability of observed differences than about extrapolating values to in vivo conditions.

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