EFFECT OF FERMENTATION OF CORN GRAIN ON DIGESTION BY RUMINANTS FULL FED HIGH CONCENTRATE DIETS

By

ERNESTO AGUIRRE OLIVAS

Ingeniero Zootecnista
Universidad Autonoma de Chihuahua
Chihuahua, Mexico
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Master of Science
New Mexico State University
Las Cruces, New Mexico
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of the Oklahoma State University
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Thesis Approved:

F. N. Owens
Thesis Adviser

D R Gill

P. L. Claypool

D. H. Wagner

Charles V. Maxwell

Norman N. Durham
Dean of the Graduate College

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CHAPTER I

INTRODUCTION

Since net energy for gain is generally cheaper from grain than from roughages, most feedlots diets contain a high percentage of grain. Consequently, efficiency of grain utilization has a large impact on the economy of the cattle feeding. Starch is the main form in which energy is stored by cereal grains and starch makes up the largest fraction (71.5%) of corn dry matter (Inglett, 1970). Increasing availability of starch will affect utilization of grain by cattle.

Various grain processing techniques have been devised to modify the structural characteristics of the corn kernel so as to improve animal performance and efficiency. In addition to grain processing techniques, many other factors affect the utilization of starch. These include level of feed intake, age of the animal, roughage source, roughage level, rumen volume, protein solubility and grain particle size. Despite these other factors, starch availability can generally be increased by grain processing. Processing is the pivot that modifies or interacts with other factors to improve the availability of starch. Benefits in cattle performance obtained from grain processing have been demonstrated by many workers (Hale,1973; Buchanan-Smith, 1976; Gill et al., 1980; Hale, 1980). Grain processing can be simple or complex. Most of the traditional grain processing

systems require a large amount of energy. For instance, popping, micronizing, exploding, flaking all require fuel for heating or steaming of the grain. As energy costs have risen, research attention has turned to less energy intensive methods to process grain for feedlot cattle while utilizing these grains as efficiently as possible (Hale, 1980). Harvesting and ensiling corn grain at a high moisture level or adding water to dry corn satisfies concerns both about energy input system and efficiency of storage and utilization of nutrients. In addition, early harvest often decreases field losses of grain and therefore is preferred by grain producers.

High moisture corn (HMC) is a relatively new product. Beeson and Perry (1958) were among the first to report that corn stored in the high moisture form resulted in improved feed efficiency. Most research since 1958 has compared HMC with corn processed by other methods. Little work has examined the effect of moisture content and fermentation on the nutritive characteristics of the grain or attempted to answer why animal efficiency is greater with HMC than dry grain.

High moisture corn received special interest the middle 70's, and interest has been renewed in the 80's. Many questions have been raised but few have been answered. To date, no ideal or standard of quality for HMC has been developed for use by feedlots similar to the cost discount systems available for dry grains and alfalfa.

The trials in this thesis were designed to determine the effect of fermentation on 1) nutrient characteristics of fermented corn, 2) animal performance and 3) site and extent of digestion in ruminant

animals. The final experiment compared site of digestion of HMC with corn subjected to other methods of processing.

CHAPTER II

REVIEW OF LITERATURE

Structure of the Corn Kernel

Corn grain is a caryopsis or berry, borne by a female inflorescence commonly known as the ear. Each ear holds upon its central stem, the cob, up to 1000 individual and similar kernels (Watson, 1967). Botanically, the corn plant is known as Zea mays Linnaeus (Inglett, 1970) and is a member of the grass family, Gramineae (Watson,1967).

Mature kernels consist of four major parts: endosperm, germ (embryo), pericarp (hull or bran), and tip cap. The relative proportions of these component parts of a typical grain of corn are presented in Table 1 and will be discussed individually.

Endosperm

The mature endosperm of a typical dent corn kernel has two principal regions: the floury or soft endosperm, which is about one third of the total weight; and horny or hard endosperm, which makes up the remainder. These proportions vary considerably, depending on the variety and protein content of the grain (Inglett, 1970). Though the demarkation line between horny and floury endosperm is morphologically imperceptible, microscopically the soft region has large cells, large round starch granules, and a relatively thin protein matrix which

ruptures during drying to form void regions. These void areas give the region its floury white appearance. In the horny region of the endosperm, the intact protein matrix is thicker and does not rupture upon drying (Watson, 1967).

Most of the endosperm consists of starch granules (Duvick, 1961), with the largest granules (10-30) in the central part and successively smaller starch granules (1-10) toward the exterior (Inglett,1970).

TABLE 1.- AVERAGE COMPOSITION OF A TYPICAL CORN KERNEL AND ITS MAJOR FRACTIONS (Dry Matter Basis)[a]

Part	Kernel %	Starch %	Protein %	Lipid %	Sugar %	Ash %
Whole grain	---	71.5	10.3	4.8	2.0	1.4
Endosperm	82.3	86.4	9.4	0.8	0.6	0.3
Germ	11.5	8.2	18.8	34.5	10.8	10.1
Bran	5.3	7.3	3.7	1.0	0.3	0.8
Tip cap	0.8	5.3	9.1	3.8	1.6	1.6

[a] Source: Inglett (1970).

The endosperm of mature dent grain contains two different types of protein: a matrix protein and a granular component embedded in the matrix (Duvick, 1961). Bodies of spherical protein range in size from near the limit of resolution of the light microscope up to 3 microns in diameter. Protein bodies are largest and most numerous in the subaleurone cells, progressively decreasing in size from the outside to the central cells of the kernel endosperm. Duvick (1961)

suggested that the protein bodies contain most of the zein in the corn endosperm. Mutant varieties of corn have kernels differ in protein composition, with certain high lysine types having few if any zein granules (Nelson et al., 1965; Wolf et al., 1967).

Germ

The germ or embryo of corn grain is 11.5% of the weight of the typical kernel (table 1) or higher in varieties selected for oil content (Watson, 1967). This portion of the seed is composed of two segments, the scutellum and the embryonic axis (Inglett, 1970). The embryonic axis, which grows into a seedling upon germination, makes up approximately 10% of the germ (Wolf et al., 1952). The scutellum is a reserve of nutrients which are quickly removed during the initial stages of seedling growth. In close contact with the endosperm is the secretory epithelium where a large number of elongated secretory cells are found (Wolf et al.,1952) which secrete enzymes, mainly alpha-amylase. During germination, these enzymes diffuse into the endosperm where they digest starch to provide nourishment for the embryo (Dure, 1960). This process also appears to be involved in the fermentation process.

Pericarp

The pericarp or bran is the smooth outer covering of the grain. It is composed of four membranes. The outer layer of dead, hollow, elongated cells are packed into a tough, dense tissue. Beneath the dense layer is a spongy layer of cross and tube cells which is continuous with the tip cap and serves to absorb water. The next

layer, known as the seed coat or testa, is a very thin suberized membrane. Finally, innermost is a tough tissue, one cell in thickness, known as the aleurone cell layer which makes up about 3% of the kernel weight (Inglett, 1970). The pericarp contains mainly cellulose and hemicellulose.

Tip cap

The smallest fragment in the corn seed is the tip cap. It connects the kernel to the cob. It is composed of star-shaped cells adapted to enhance the absorption of water. A black tissue located at the point of attachment to the germ is known as the hilar layer. Water absorption is affected by the concentration of pigments and the hilar presumably serves as a sealing mechanism when the kernel is mature (Bradbury et al., 1962). Since the tip cap is very small portion of the kernel has little nutritional importance.

Importance and Structure of Corn Grain Starch

Starch is the principal food reserve material of all higher plants. Starch granules are insoluble in cold water and particles are known as plastids. The type of plastids, and the corresponding starches, may be classified as amyloplasts and chloroplasts (Banks and Greenwood, 1975). Nutritionally and commercially, the starch found in the amyloplasts is of primary interest. This polysaccharide is easily assimilated and constitutes an important source of energy for humans and animals. Plant starch is universally found in leaves, roots, tubers and seeds (Banks and Greenwood, 1975). More than 50% of the carbohydrate ingested by humans is starch (Stryer, 1981) and the same

is true for feedlot ruminant animals. Only fats have a higher energy content per unit of weight than starch. Proteins have a similar amount of energy per unit of dry weight but, in nature, are extensively hydrated. Further, the net energy yield of protein is reduced due to the energy content of protein breakdown products (French, 1973).

Starch in nature comes in two forms. Unbranched starch, known as amylose, consists of glucose residues linked by alpha-1,4 covalent bonds. Branched starch, or amylopectin, in addition to the glucosidic alpha-1,4 bonds, has alpha-1,6 bonds in proportion of about 1:30. Hence, it has a low degree of branching (Stryer, 1981). Several authors have searched for other types of branching, but only alpha-1,6 branch bonds have been found in native starches (French, 1973). The proportion of amylose and amylopectin can varying greatly among plant species (Rooney and Clark, 1968).

Starch Digestion by Animals

Starch Digestion by Non-ruminant Animals

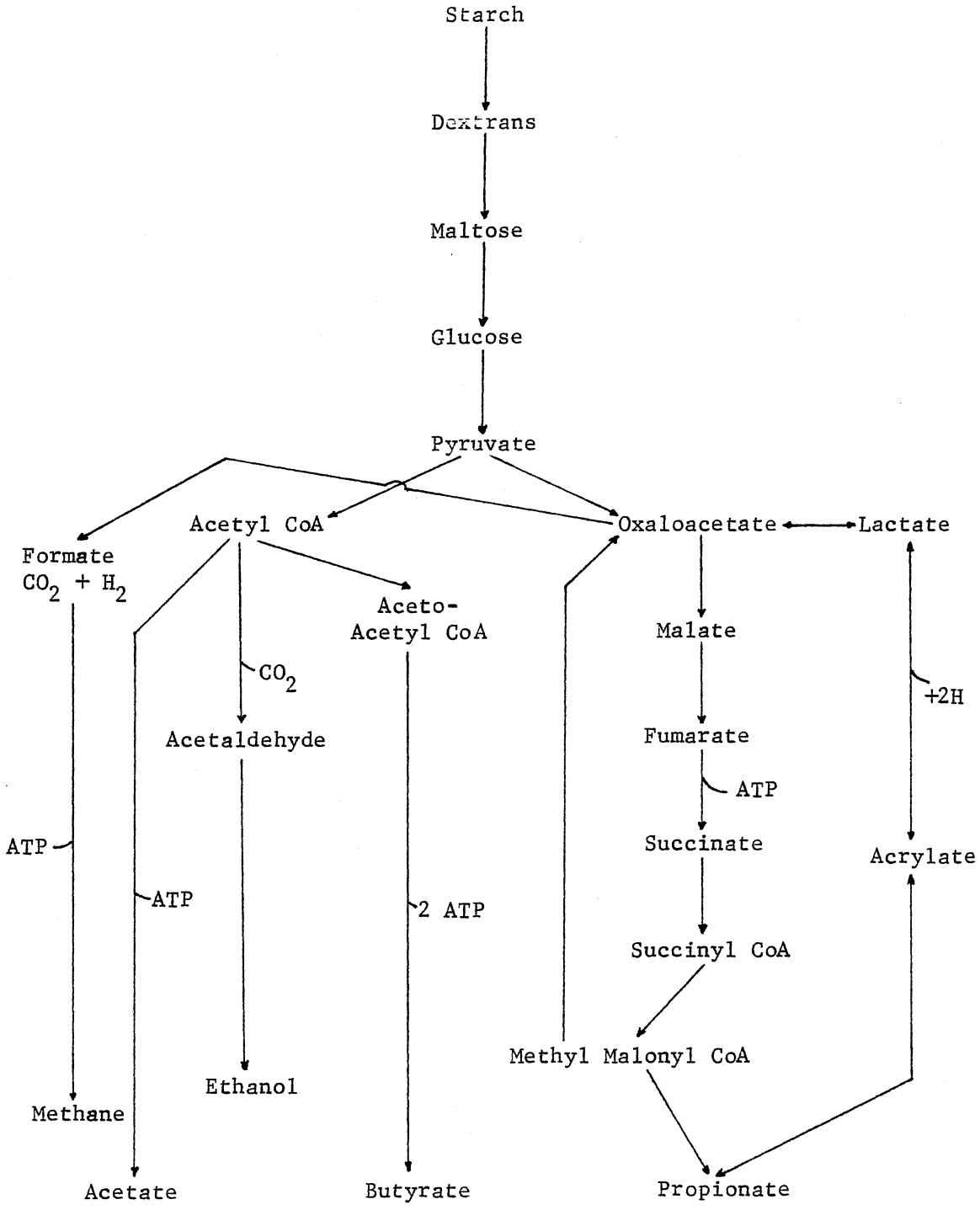
The following review of starch digestion was summarized primarily from Stryer (1981). The enzyme which hydrolyzes alpha-1,4 linkages of amylopectin and amylose is alpha-amylase. This enzyme is produced by salivary glands in some species and by the pancreas by all species. Maltose, maltotriose and alpha-dextrin are formed by breakdown of the internal alpha-1,4 linkages. Maltose consists of two glucose molecules linked by alpha-1,4-bonds and maltotriose consists of three of glucose molecules. Maltase is the enzyme which hydrolyzes of maltose and maltotriose to glucose.

Alpha-dextrin consists of several glucose units joined by alpha-1,6 and alpha-1,4 bonds. Alpha-dextrinase hydrolyzes alpha-dextrin to glucose. Another type of amylase found in malt, beta-amylase, hydrolyzes starch only to maltose. Beta-amylase acts only on residues at the non-reducing terminus.

Ruminal Digestion

Carbohydrate digestion in the rumen has been reviewed by many different workers (McAllan and Smith, 1974; Church, 1976; Kronfeld and Van Soest, 1976; Morrison, 1979; Russell and Hespell, 1981; Van Soest, 1982) and for starches is summarized below. Degradation and fermentation of polysaccharides in the rumen can be visualized in three stages. First, microorganisms attach to food particles and disassociate the polymers of carbohydrates from the structural matrix of plant cells. Both bacteria and protozoa are involved (Amos and Akin, 1979). The second stage involves hydrolysis of the polymers released in the first stage to smaller saccharides. This step is catalyzed by a great number of enzymes found extracellularly. Small saccharides are absorbed by microbial cells. Finally, intracellular enzymes ferment small saccharides. Joyner and Baldwin (1966) and Wallnofer et al. (1966) have shown that glucose and other hexoses are degraded by the Embden-Meyerhof-Parnas pathway by microbes in the rumen.

The major intermediate intracellular products formed from hexose or pentose degradation are phosphoenolpyruvate and pyruvate (Russell and Hespell, 1981). These compounds are transformed into different products of fermentation (Figure 1) by several pathways. Some



Source: Van Soest, (1982).

Figure 1. Generalized Pathway for Ruminal Degradation and Fermentation of Starch

products (lactate, ethanol, succinate) rarely accumulate in the rumen supposedly since they are instantly absorbed through the rumen wall or immediately fermented by other microbial species to other compounds.

Intestinal Digestion and Absorption

The pathway of starch degradation in the post-ruminal section of the digestive tract is similar to that described for the rumen except that the enzymes are produced and secreted by the animal. Enzymes involved in starch digestion in the small intestine are the amylases and maltases of pancreatic juice and the amylase, maltase and oligo-1:6-glucosidase of the intestinal mucosa.

Summarizing the results of four experiments, Armstrong and Beever (1969) estimated that with cattle fed diets containing ground corn, 32% of the dietary starch reached the small intestine and 83% of this was apparently digested in the small intestine. These portions will increase as the percentage of corn in the diet increases. Genetic variation may also affect the susceptibility to enzyme hydrolysis (Waldo, 1973) as would grain processing, level of feed intake and the variety of factors listed previously.

In addition to starch from the diet, ruminal microbes store carbohydrate as an energy reserve and contribute to the flow of starch to the small intestine. Measurements of microbial carbohydrate are not extremely accurate (Jouany and Thivend, 1972b; McAllan and Smith, 1974). However, regardless of the source of carbohydrate, starch reaching the small intestine is hydrolyzed to glucose and supposedly are absorbed as glucose. Glucose absorbed from the small intestine should meet the glucose requirement of ruminants according to the

calculations presented by Armstrong and Beever (1969). Recently, blood measurements by Huntington (1981) failed to detect glucose uptake by the portal system in steers. He suggested that absorption of glucose is small or non-existent. Further study of this theory is needed.

Supposedly, most of the starch reaching the small intestine is hydrolyzed in the first half of the jejunum since activities of intestinal amylase and maltase are highest in this portion of the digestive tract (Wright et al., 1966; Hembry et al., 1967;), possibly due to the pH optima for those enzymes (Long, 1961; Lenox and Garton, 1968). That the intestinal pH is too low for optimal amylase activity was proposed in controversial studies by Wheeler and Noller (1977). Starch escaping digestion in the small intestine passes to the large intestine where is attacked by microorganisms in a manner similar to degradation in the rumen.

Fermentation as a Corn Processing System

During the decade of the 60's, the beef cattle feedlot industry became highly mechanized and more efficient. One way that efficiency was increased was through the use of high concentrate diets. During this decade, prices of fossil fuel were relatively low and fuel was abundant. Consequently, as grain processing systems developed, energy consumption was of little concern. Subsequent increases in fuel prices, exceeding 100% in the past 10 years, have increased concern about energy consumption; processing methods requiring less energy input became of greater interest. Harvest of grain in a high moisture state and storage by fermentation is an inexpensive process relative

to heat processing method.

In practice, HMC can be formed by two different methods. Most HMC is harvested at a moisture level of between 25 and 32%. HMC can also be formed by adding water to drier corn to increase the moisture level to the levels above. When this process is started with corn less than 16% moisture, the latter procedure is called reconstitution, but often water is added to corn harvested at higher moisture contents, too.

Corn is reconstituted to raise the moisture level so as to assure that the corn will ferment. The amount of fermentation appears to be directly proportional to the moisture content (Goodrich et al., 1975; Goodrich and Meiske, 1976; Thornton et al., 1977b). HMC must be stored in a low oxygen environment to permit fermentation to occur. With fermentation, physical and chemical nature of the kernel changes due to activity of microbial enzymes and presence of fermentation acids.

To permit fermentation, material is placed in an oxygen limiting structure called a silo. Several different types of silos have been developed which range from upright cylinders to deep or shallow bins and piles covered with plastic. Shallow bins are sometimes called bunker silos and, relative to other silos, are relatively low in cost. The terms "bin", "silo" and "bunker" have different meanings in different parts of the world and may vary from one author to another.

Feeders with small herds should consider upright silos to reduce the amount of surface area of silage exposed for aerobic deterioration. As metal silos have been constructed taller and with larger diameters, the incidence of structural errors in metal grain bins has increased. Since this matter is of concern among design

engineers, computer programs have been developed to estimate the wall pressure and average bulk densities of materials in silos (Ross et al., 1979). Many types of metal or concrete upright silos are available commercially which will satisfy different capacity demands and assure an adequate oxygen-limiting environment to store and ferment HMC.

Horizontal silos are adaptable to large feedlots and some small farms. Silos are special structures, having special problems not found in regular building design. These problems include drainage, acid deterioration and stresses from static and dynamic loading. Therefore, The American Concrete Institute (ACI, 1975) provides material, design and construction recommendations for reinforced silos.

Grain is often ground or rolled before ensiling to permit packing, to exclude air and prevent air from penetrating the mass. The components of the grinding system have been described by Paine (1967) as follows. A transitory unloading area is required to facilitate rapid unloading of trucks carrying the grain to the milling area. The capacity of this transitory unloading area should be about three days supply for the mill at its maximum rate. The transitory unloading area should be organized so that mobile equipment can push grain directly into conveying equipment. A carrier is needed to move the stored grain into the milling device. Roller mills and tub grinders are commonly used for milling. It is important to maintain a full load on the mill as motors are most efficient at full load though care must be taken to avoid overloading motors.

The load on the milling equipment differs with moisture content

of the grain. The higher the moisture, the slower the milling rate. Commercial devices to open and close the gate according to the load on the motor are available. Sometimes additional water is required, even with the grain being harvested at a high moisture level. Water can be added with spray nozzles with the water flow controlled by valves to meter the water to obtain the desired moisture level. When the grain is delivered to the silo area, it is pushed into the pile by a tractor which also serves to pack the silage.

Starch Modification

On addition of water, starch granules swell absorbing 50% or more of their weight as water. Distributed among the starch granules, water facilitates free access of starch to enzymes. Granule swelling is reversible, and after cooling and drying, the starch granules seem to be essentially unaltered. However, if wetted starch is heated to 60 to 80 C, most starch undergoes an irreversible swelling or gelatinization, in which starch granules lose their crystallinity (French, 1973). Gelatinization does not occur with ensiled HMC since the temperature does not reach that point. But other physical and chemical changes occur which alter starch digestibility and availability.

When HMC grain is well packed in the silo, enough oxygen remains present to initiate but not enough to maintain germination. To continue germination with development of the radicle and coleoptide, oxygen is absolutely necessarily; thus the process abates when oxygen is depleted (Sullins et al., 1971). To provide energy for the embryo during germination, cells of the germ secrete alpha-amylase to

hydrolyze starch. In sorghum grain, Sullins et al. (1971) found that high moisture level has a major effect on the structure of the grain at the subcellular level. At higher moisture levels, subcellular components showed a higher degree of disorder and the protein matrix was disrupted, resulting in liberation of starch granules and protein bodies.

A similar disruptive process occurs with malting of barley (Luchsinger, 1966). Water can be used to extract active alpha-amylase whose production is activated by gibberelins secreted by the embryo. Degradation of the endosperm is decreased when water is not present. The gibberelic acid is not able to move from the embryo to the aleurone layer to activate the necessary enzymes. However, when water is added during reconstitution, proteolytic and amylolytic enzymes present will modify the starch structure and the protein matrix (Van Overbeek, 1966).

Germination requires water, oxygen and heat. McGinty et al. (1968) estimated that about 21 days are required to deplete the oxygen in the silo. At this time, the germination process would end since under anaerobic conditions the production of alpha-amylase is not stimulated by gibberelic acid (Chandra and Varner, 1963; Siegel et al., 1963). However, de novo synthesis of alpha-amylase continues (Varner, 1964) after germination has ceased. At this point, the process called fermentation begins. The estimation of 21 days seems to be extremely long. Owens et al. (1970a) have demonstrated that 75% of the total fermentation gas production is obtained within 2.5 to 3 days after ensiling whole plant corn material.

Fermentation as defined by Stryer (1981) is an ATP-generating

process in which organic compounds act as both donors and acceptors of electrons. First recognized by Louis Pasteur, fermentation is life in the absence of oxygen. Fermentation is now recognized as a vital process for life in all animals. Many types of fermentation are possible depending on the amounts and types of substrates available for decomposition.

Fermentation in ensiled corn grain follows the Embden-Meyerhof pathway (Metzler, 1977) as illustrated in Figure 1. Pyruvate is reduced to lactate, the major end product of fermentation, by lactate dehydrogenase. In a similar reaction, pyruvate also is converted to acetaldehyde which is reduced to ethanol or transformed to lactate. Carbon dioxide is released and small amounts of volatile fatty acids are formed.

Another important reaction which can occur in ensiled HMC and usually is underestimated is the Maillard reaction in which aldehyde, ketones and reducing sugars condense with amines, amino acids, peptides and proteins. This reaction also is called non-enzymatic browning. Mauron (1981) divided the Maillard reaction into three steps: the early reaction which corresponds to the chemically well-defined stages without browning; the advanced reaction involves the innumerable reactions leading to volatile or soluble substances and the third stage leads to insoluble brown polymers. The most important reaction nutritionally is the first stage in which carbohydrates condense with amino acids. Condensed amino acids are indigestible. The most reactive amino acids are those with a nucleophilic group such as lysine, methionine and the aromatic amino acids (Van Soest, 1982). The final polymerized product is a brown

substance having many of the physical and chemical properties of lignin.

Although the Maillard reaction has not been discussed in HMC experiments, it may occur at the temperature of a silo. Mauron (1981) reported that the rate of reaction between casein and glucose increased 40,000-fold when temperature increased from 0 to 80 C. Duration of heating is another important factor which controls the extent of the Maillard reaction. Hurrell and Carpenter (1974) found that an albumin-glucose mix reacts 85% by heating for 15 minutes at 121 C and the same mix reacted 76% after 30 days of storage at 37 C. Temperatures above 37 C may be found in ensiled HMC grain. Water plays an important role in the browning reaction but it can inhibit the reaction. Wolfrom and Rooney (1953) did not observe browning when the moisture content was zero or above 90% water, but was maximum at 30% moisture, a typical moisture content for ensiled HMC. Finally, pH plays a role in the browning reaction, decreasing with acid and increasing with alkaline pH. However, phosphate and citrate work as buffers and favor the reaction (Saunders and Jervis, 1966).

Protein Modification

A sizeable portion of the total nitrogen in the corn kernel is present as low molecular weight non-protein nitrogen (NPN) compounds such as free amino acids, amines, amides, quaternary nitrogen compounds, purines and pyrimidines (Christianson et al., 1960). Christianson et al. (1965) showed that in each portion of the corn kernel, the most prevalent form of NPN is free amino acids, composing about 61% of the NPN in the germ, 50% in the endosperm and 29% in the

bran. Quaternary nitrogen compounds made up 9% of the NPN in the germ but only 5% of the NPN in the endosperm. Heterocyclic compounds made up only about 5% of both endosperm and germ NPN and undetectable quantities of the NPN in bran.

In addition to carbohydrases, proteases are present in the kernel. Proteases hydrolyze protein during germination, and fermentation processes increase the proportion of soluble protein. Hamad and Fields (1979) found that the amount of lysine in wheat and barley increased during the germination process. During fermentation, lysine content of barley, oats, rice, millet and corn also increased. Amounts of available lysine increased as well, especially with germination.

More recently, Phillip and Buchanan-Smith (1982) found that the free amino acid content in ensiled material increased with fermentation. Previously Ohshima et al. (1979) working with grasses and legumes had found that alanine was the amino acid which increased most. In silages, there was net synthesis of alanine (Barry et al., 1978). Similar results were reported by Bergen et al. (1974) with ensiled whole corn plants. They found that amino acid content continued to increase with fermentation even though proteolysis declined by more than 75% when fermentation began. Lessard et al. (1978) found that amino acid content was increased with anaerobic storage, especially for the essential amino acids isoleucine, lysine, threonine and valine. Amino acid responses to fermentation appear similar among grains, grasses and legumes.

The total protein content of HMC remains quite constant during fermentation (Prigge et al., 1976a) though protein is transformed from

insoluble to soluble protein and soluble protein into non-protein forms. The content of soluble nitrogen increased significantly with fermentation (Goodrich et al., 1975; Prigge et al., 1976a; Thornton et al., 1977b) while the amount of true protein is decreased considerably (Lopez et al., 1970; Johnson et al., 1967). In contrast, Owens et al. (1969) and Lessard et al. (1978) found that true protein content increased with fermentation, especially when urea was added to the ensilage. This may reflect microbial synthesis of protein. Solubilization of nitrogen in HMC appears to be less dependent on bacterial action than on chemical and physical factors, especially acidity, osmolarity and hypertonicity during fermentation (Prigge et al., 1976b).

Nutritionally, amine-N can be important as it may depress feed intake of the animal. This compound is formed during fermentation. Ohshima et al. (1979) working with ryegrass and lucerne found about 11% of the total nitrogen in silage was amine-N and Phillip and Buchanan-Smith (1982) found that 5% of the total nitrogen in whole-plant corn silage was amine-N.

Effect of Fermented Corn on Animal Performance

Commercially, corn producers attempt to maximize yields by utilizing land as fully as possible and by reducing loss or damage caused by adverse environmental conditions such as ear drop with severe weather and early frost. For maximum yield, harvest must wait until grain is physiological mature. Beyond this point, yield declines. As producers wait for grain to dry in the field to a storable moisture content, weathering results in ear drop and stalk

damage while insects, birds and rodents consume some of the crop. At physiological maturity, the moisture level of grain can range from 25 to 40%. After this point, the kernel is sealed from the ear so the nutrient content of the kernel is maximum and on a dry matter basis remains constant (Thornton et al., 1969). With harvesting at a high moisture level, field losses can be reduced by 5 to 10% (Gill, 1980).

Typically, cattle feeders purchase HMC from local corn producers. It is normally trucked to the feed yard at harvest time. This eliminates freight and elevator fees often incurred with harvest and storage of grain in the dry form. Cost of storage in the high moisture form often is lower than in the dry form. For grain harvested at a high moisture level, storage in the dry form requires investments in equipment and fuel to dry the grain (Gill, 1980). Finally, HMC often is used by cattle more efficiently than dry corn grain.

Fermentation only occurs when feeds are stored in an oxygen-limiting environment with a certain level of water. If materials, such as urea, which neutralize or buffer the acids produced during fermentation, this process continues for a longer period of time and greater amounts of fermentation products are formed (Owens et al., 1970a). Since animal efficiency usually is greater with fermented HMC than dry corn, changes during fermentation must improve nutrient availability.

Physical and chemical changes with fermentation can depress palatability or acceptability. Further studies on feed intake of HMC are needed to understand why intake of HMC is often greater than of dry corn at lower moisture levels (Teeter et al, 1979) but lower than

of dry corn at higher moisture levels (Sprague, 1976). The acids, NPN and ethanol produced during fermentation may be involved in taste or acceptance, or the higher energy availability or levels of acid produced in the rumen may depress intake.

Lamb Performance

Few reports have been published on performance of lambs fed HMC. Harpster et al. (1975) fed HMC containing 12.2 or 36.8% moisture to lambs. Dry matter intake was 35.7% greater for HMC than dry corn, but lambs fed dried corn gained faster than lambs fed HMC. Efficiency of gain was 14.9% greater for lambs fed HMC.

Phillip and Buchanan-Smith (1982) fed lambs fermented whole corn plants to study the influence of amino-N concentrations on dry matter intake. Levels of amine-N and amino acids of fresh and ensiled corn were not related to voluntary feed intake. Nevertheless, NPN compounds may reduce feed intake with some corn silages. Similarly, Bergen et al. (1974) fed ensiled corn forage to mature sheep. Ad libitum dry matter intake did not differ from intake of dry forage despite greater protein degradation and higher NPN concentrations.

Beef Cattle Performance

Beeson and Perry (1958) compared high moisture ear corn (32.2 % moisture) with dry ear corn for beef steers. Feed intake, daily gains and efficiencies were greater with fermented high moisture ear corn. Bloomfield et al. (1959) allowed HMC (27.5 % moisture) to ferment in plastic bags for eight months and fed it to the cattle, sheep and swine. Feed intake, average daily gain and efficiency were greater

with HMC than dry corn. They suggested that the improvement was due to a greater intake of the fermented grain. In contrast, Heuberger et al. (1959) found that cattle fed corn with 36% moisture had depressed feed intake as well as rate and efficiency of gain. However, they found that steers may be placed on full feed faster with HMC (33% moisture) than dry corn.

More recent experiments with HMC with high concentrate diets have generally obtained improvements in feed efficiency between 6 and 25% (McGinty et al., 1968; Riggs and McGinty, 1970; Henderson and Bergen, 1970; Tonroy et al., 1974; Teeter et al., 1979). Hale (1980) reviewed 50 feeding trials to examine the effect of corn processing systems on performance of feedlot cattle. A summary of his data is presented in Table 2. Generally, corn processing method had little effect on daily gain, though gains slightly favored early harvested and reconstituted corn over dry-rolled, flaked and whole shelled corn. Steam flaking of corn (SFC) reduced feed intake by 8.7% and increased efficiency of feed use by 8.7%. Fermentation reduced feed intake by 3.3% and increased efficiency of feed use by 6.5%.

Some of the superiority in energetic efficiency of HMC may be attributed to errors during analysis of dry matter since fermented grains contain volatile acids and ethanol (Goodrich and Meiske, 1971). These errors also increase the apparent losses of dry matter attributed to fermentation. Gill (1983) indicated that the fermentation losses with HMC are only about 3%. This loss must be subtracted from the HMC system to calculate energetic efficiency. However, some 7 to 15% must be added for the increased dry matter yield per unit of land harvested in the high moisture form (Gill,

1983). Overall, HMC shows its greatest advantage when efficiency of cattle feeding is calculated per unit of land harvested.

TABLE 2.- COMPARISON OF DIFFERENT CORN PROCESSING SYSTEMS[a]

Item	Processing Method			
	Dry-rolled	Flaked	Whole-Shelled	Early Harvest & Reconst
Daily gain, kg.	1.25	1.25	1.25	1.29
Daily intake, kg.	8.60	7.91	8.58	8.31
Reduction, %	---	8.7	---	3.3
Feed/kg gain, kg.	6.88	6.33	6.86	6.44
Grain level, %	74	74	78	80
Improvement in efficiency				
ration, %	---	8.7	---	6.5
grain, %	---	10.0	---	8.1

[a] Adapted from Hale, 1980.

Hoffman and Self (1975) compared corn dried artificially and stored in conventional bins against corn stored as high-moisture whole grain in oxygen-limiting silos and corn stored in the high moisture ground form in concrete-stave silo. No differences in feed intake were reported, but of the three methods of storage, the oxygen-limiting structure was the most efficient. Ensiled HMC was a desirable economical alternative to artificially dried corn.

Influence of Fermentation on Nutrient Digestibility

Rate and efficiency of ruminant animals fed high or all concentrate diet are generally slightly superior when diets contain

HMC rather than dry corn. The improvement may be partially due to loss of volatiles during drying, but a portion also may be due to greater digestibility of protein and starch of the corn kernel. Softening during fermentation may facilitate greater digestion or absorption. Swelling with water may facilitate enzymatic action or may modify the particle size of food and alter the rumen turnover rate or flow rate through the total digestive tract. Level and source of roughage, feed additives and preservatives might influence these factors, also.

In situ Digestibility

The dacron bag technique has been useful to study ruminal dry matter and protein disappearance (Galyean et al., 1977; Mehrez and Orskov, 1977; Crawford et al., 1978; Barney et al., 1981). Since fermentation solubilizes protein, greater washout of this material might be expected. Most types of soluble protein are rapidly attacked in the rumen which reduces the potential for protein bypass (Owens, 1978). Crawford et al. (1978) found very rapid initial disappearance in situ of soluble nitrogen from corn silage. A large portion of the soluble nitrogen is NPN derived from breakdown of protein during fermentation. Prigge et al. (1978) found that HMC at 25.3 % moisture had 64% of its protein in a soluble form. They calculated that 44% of total protein was degraded in the rumen. In contrast, Crawford et al. (1978) found only 8.9% N loss in situ with dry corn containing 5.9% soluble protein. Stern and Satter (1982) found a positive correlation between ruminal protein degradation and N solubility. However, Zinn and Owens (1983) and Owens and Bergen (1983) suggested that both

solubility and in situ degradation must be considered in estimating protein bypass.

Increasing the N solubility of HMC may be useful as the N, like dietary urea, would be available for bacteria to synthesize protein. Though insoluble N is desirable for increasing protein bypass to the intestine, not all insoluble protein is digested. For instance, unprocessed feather meal and hair protein is highly bypassed to the lower tract but is poorly utilized due to its low digestibility. Theoretically, all protein of the cell contents and some portion attached to hemicellulose will be digested in the rumen (Owens, 1978). Also, the protein quality from corn may be improved if it is transformed into bacterial protein.

Galyean et al. (1977) studied dry matter disappearance (DMD) in situ. DMD was higher for HMC than for dry corn at various particle sizes and incubation times. Hence, HMC appears to be more rapidly and extensively degraded in the rumen. This may change ruminal conditions, as well.

In vitro Digestibility

Digestibility of HMC also has been studied in vitro. Utilization of total carbohydrates was high and most of the soluble N from HMC was available in vitro (Danley and Vetter, 1974a). These researchers suggested that rumen microorganisms can degrade greater proportions of the matrix protein from HMC than dry corn. Ruminal ammonia concentrations might not reflect this, however, since readily available carbohydrates increase microbial ammonia-N uptake and synthesis of bacterial protein (Broderick, 1982).

Tonroy and Perry (1974) incubated dry corn, ensiled HMC and ensiled reconstituted HMC in vitro. DMD was higher for ensiled HMC than for dry or reconstituted HMC. Starch digestion also favored HMC. Earlier, Neuhaus and Totusek (1971) working with sorghum grain, found greater DMD for wetter grain, but they found no difference between grain harvested with high level of water and reconstituted grain.

Due to the drastic changes of ammonia concentration in vitro, predictions of ruminal protein degradation from in vitro ammonia release is hazardous. Energy digestibility may be more easily predicted from in vitro measurements. Hale (1973) concluded that in vitro gas production, enzymatic starch digestion, DMD and volatile fatty acid production appear to be reliable indicators of in vivo digestibility and utilization. In contrast, White et al. (1973) comparing raw, roasted, fatty acid treated, high moisture (25 and 30%) and reconstituted corn (25 and 30%), found that roasting decreased in vitro DMD of both raw corn and corn stored at a high moisture level. But in vivo, no differences in dry matter, starch, crude protein and energy availability from these corn types were observed.

In vivo Digestibility

Level of water in fermented HMC grain appears to alter digestibility. Corn containing 20% water may give lower efficiency than either dry corn or corn with more than 27% moisture. Galyean et al. (1976) fed corn in the dry or HMC (28.5% moisture) form and observed greater digestibilities for starch, DM and OM with HMC. Dry rolled corn (86% DM), low moisture corn (79.8% DM) and high moisture (73% DM) were compared by Teeter et al. (1979). Digestibility

coefficients tended to be higher with HMC for DM, organic matter, starch and protein. Fecal pH decreased as the percent of the starch present in feces increased. Since more starch is digested with HMC, the amount of energy available to the animal may be increased (Kiesling et al., 1973. Galyean et al., 1975). Owens and Thornton (1976) summarized 36 experiments with HMC and calculated energy values from animal weights, gains and feed intakes. The higher the moisture in HMC, the greater the metabolizable energy (ME), however, higher moistures also reduced feed intake.

The available literature suggests that fermentation is similar whether water is added to reconstitute dry grain or the grain is harvested containing a higher level of moisture. Gill et al. (1982) found that corn grain harvested at 24% moisture and reconstituted to 31% moisture had the same feeding value as grain harvested at 31% moisture. However, the comparisons above have used corn grain harvested above 18% moisture. Whether similar results would be found with addition of moisture to corn dried to 15% moisture in the field or with added heat has not been determined.

Digestibility of HMC may change with level of roughage in the diet. Acidosis problems can occur with high grain rations (Dunlop, 1970), so higher amounts of fiber usually are added to high concentrate diets to stimulating salivation and thereby to increase the ruminal pH. Presence of fiber in the rumen also increases rumination which may increase the extent of digestion. Gill et al. (1981) fed different levels of roughage (8, 12, 16, 20 and 24% of diet DM) to steers with HMC or steam flaked corn (SF). Rate and efficiency of gain were greatest for steers for SF at 8% roughage and with HMC at

16% roughage. They concluded that level of roughage may be less important than the form and type of roughage in the diet.

Addition of up to 24% roughage to the diet generally will not reduce average daily gain if intake increases appropriately to compensate for the dilution of energy (Owens and Gill, 1980). However, DM and N digestibility in the rumen will decrease as roughage is added (Cole et al., 1976a). This depression is less evident with processed than with whole corn. Rust (1983) fed steers corn with various roughages at higher levels of intake (2% of body weight). Source of roughage did not affect the digestibility of OM, starch, nitrogen and acid detergent fiber (ADF), but with 50% added roughage, digestibility was influenced by the type of roughage.

Depending on source of roughage added, starch digestibility can either decrease or increase. Teeter et al. (1981) found that addition of 10% cottonseed hulls to the diet increased starch digestion of whole corn while Cole et al. (1976a) found that added hulls reduced starch digestibility from rolled corn.

Utilization of N from HMC has been studied by Prigge (1976) and Prigge et al. (1978). Generally, N digestibility is greater with HMC than dry corn. But animals fed HMC often excrete less N in the urine which calculates to greater N retention by animals fed HMC than dry corn. Microorganisms in the rumen grew more efficiently when the HMC was fed in the whole compared with the ground form.

A variety of N supplements have been tested, also. Addition of N sources (urea, biuret or soybean meal) at ensiling increased and prolonged fermentation of whole corn plant material (Owens et al., 1970a). Addition of urea always increases the amount of crude

protein, but also may increase the amount of true protein present (Owens et al., 1969; Owens et al., 1970b; Lessard et al., 1978), possibly through inhibition of proteolytic enzymes in the silage. To measure the effect of adding urea to HMC at feeding time, Thornton et al. (1977c) fed steers HMC with urea or soybean meal as the source of supplemental N. Animals fed supplements with more soluble N had lower gains, but added urea did not reduce feed consumption. Table 3 reviews the effects of feeding urea or soybean meal as N sources with HMC. Since plasma urea levels were lower with HMC than with dry corn, urea appeared to be utilized more efficiently with HMC (Prigge et al., 1976b).

TABLE 3.- COMPARISON OF N RETENTION OF DRY (DC) AND HMC RATIONS WITH SOYBEAN MEAL (SBM) OR UREA AS SUPPLEMENTAL N SOURCES [a]

Item	DC + SBM	DC + UREA	HMC + SBM	HMC + UREA
DM intake, g/day $kg^{.75}$	51.2	48.7	51.9	52.4
N, intake, g/day $kg^{.75}$	1.04	1.03	1.01	.98
Digestible DM, %	74.2	77.3	74.4	73.5
Digestible protein, %	66.5	68.7	62.5	62.4
Urinary N, g/day $kg^{.75}$	.39[b]	.43[b]	.30[c]	.28[c]
N, retained, g/day $kg^{.75}$	.32[b]	.34[bc]	.35[c]	.36[c]
N, retained/absorbed, %	46.4[b]	44.0[b]	56.0[c]	59.1[c]

[a] From Prigge et al. (1976b).

[b,c] Means in a row with different superscript differ ($P<.05$).

Additional experiments (Owens et al., 1979) were conducted with

various types of additives of fermentation aids for HMC. These included preservatives and acids to avoid spoilage or drugs to improve the utilization of HMC. Six commercial additives as well as propionate, monensin, formaldehyde, bentonite and NH_4OH were added to HMC (73.1% DM) at ensiling time. One of the commercial additives and propionic acid inhibited fermentation and mold growth. These materials also inhibited ruminal fermentation. Other additives did not affect fermentation. If the HMC was properly packed, additives showed no benefit. In another trial (Thornton et al., 1977b) formaldehyde was added at ensiling time to HMC at levels of .2, .3 and .5%. Solubilization of N from HMC was reduced, but ruminal and total digestion of DM, starch and N also were depressed. Increased protein bypass was not useful, possibly since corn protein has a lower quality than microbial protein. Consequently, formaldehyde does not appear to improve utilization of HMC by cattle (Thornton et al., 1979).

Tonroy et al. (1974) added acetic and propionic acids as preservatives for HMC. They found no improvement in digestibility by steers fed HMC. Similar results were reported with lambs (Polzin et al., 1972). In contrast, Harpster et al. (1975) found that addition of propionic acid reduced digestibility of the nitrogen free extract (NFE) fraction of HMC.

Rust et al. (1979) reported that response to addition of monensin to diets was less with HMC than dry corn diets. Digestibilities increases with added monensin for DM, OM, starch and N were greater with dry corn than HMC. Utley et al. (1977) also found that monensin did not affect digestibility of HMC.

Other Corn Processing Systems

Corn can be fed in the HMC, SF, rolled (RC) or whole unprocessed form. One of the most common but most expensive methods for processing grain is steam flaking. SF is an extension of the steam rolling process. The flaking process consists of steam-cooking or heating the shelled corn in a chamber between 90 to 100 C for 15 to 30 min at atmospheric pressure. During this period, the moisture content of the corn increases to 18 to 20%. The steamed grain is then passed through the rollers to produce a flake. Rollers should be as close as possible to obtain a thin, high quality flake. Hale (1980) recommends that the flaked corn should weigh between .523 and .565 kg per liter (26 to 28 pounds per bushel). If SF is to be stored for more than 24 hours, it should be dried. If fed every day, SF need not be dried.

During ensiling, starch granules swell in a reversible fashion. Heat used in the flaking system results in an irreversible swelling called gelatinization. Gelatinization of the starch has been used to measured the changes which occur during processing (Hale, 1973) and is an index of quality of flaked grains (Hale, 1980). If all of the starch is gelatinized, performance of finishing steers is poor (DeBie and Woods, 1964). Performance is optimum when the degree of gelatinization is between 40 and 50% (Hale, 1980).

Steam flaking alters starch granules so that they resemble erythrocytes or shapeless conglomerates. Protein bodies may remain intact, but protein surrounding and between individual starch granules is disrupted. Thus, gelatinization converts starch to a form more vulnerable to amylolytic action (Harbers, 1975). Protein may be more exposed for attack, but the heat may bind some of the protein to the

carbohydrates reducing its availability in the rumen.

The process of flaking usually improves feed efficiency (Table 2) and in most trials always has given higher efficiencies than HMC. Gill (1983) ranked SFC as first among the methods for increasing efficiency of feed use.

Rolled corn (RC) is usually considered to be similar to ground corn (Hale, 1980; Gill, 1983). However, dry rolling usually produces a more flocculent, less powdery and dusty product than grinding. This could be advantageous since dusty feeds are often less acceptable to animal and result in lower feed intake and rate of gain (Owens and Gill, 1980). Dry rolling is recommended for small-farmer operations (Hale, 1980). The improvement from rolling the grain is due to physical disruption which reduces the particle size and exposes more surface for bacterial and enzymatic attack.

In summary, HMC is not a single product with a single value. Digestibility of DM and OM in the total tract appears to decrease with intermediate levels of moisture (20 to 25%) but increases with a higher level of moisture (over 28%). If the most efficient site for utilization of starch by the animal is in small intestine, HMC and SFC should have a disadvantage. Such an effect is not observed in most of the feeding trials. Considering animal response without economic analysis, corn is improved by about 8.1% by processing in the HMC form or by about 10.9% by steam flaking (Table 2). One advantage for WSC is the low investment of equipment and labor required. With uncertainty about future costs of energy and labor, the most economical means of processing corn may change in the future as it has in the past.

CHAPTER III

EFFECT OF MOISTURE CONTENT ON CHEMICAL COMPOSITION OF FERMENTED HIGH MOISTURE CORN GRAIN

Summary

Corn grain, harvested at 21 to 35 percent water, was reconstituted to various moisture levels and allowed to ferment for 60 days. During fermentation, pH and content of DM and OM declined ($P<.01$) while soluble nitrogen and available starch content increased ($P<.01$ and $P<.10$, respectively). Soluble protein, apparent starch content and availability of the fermented grain increased ($P<.01$) as moisture content of the grain increased while pH was inversely related to final moisture content. Results indicate that the extent of fermentation of corn grain depends on moisture content of the fermented grain and that differences should alter nutritive value of the final product.

Introduction

High moisture corn grain (HMC) is typically harvested between 21 and 35% moisture and ensiled for subsequent feeding to livestock. The nutritive value is quite variable, part of which may be related to the moisture content of HMC (Thornton et al., 1977a). Moisture content at harvest and addition of water to the harvested grain has been shown to affect animal performance (Galyean et al., 1976;

Teeter et al., 1979; Gill et al., 1983) though reasons for the difference have not been determined. Very high moisture levels will reduce feed intake and reduce rate of gain of feedlot steers (Sprague and Breniman, 1969), while with dry HMC, feed intake may be high and efficiency of feed use may be poor (Teeter et al., 1979). No ideal moisture content has been determined, so both researchers and livestockmen are uncertain about the optimum time for harvest and the potential benefits of reconstitution (addition of water at ensiling time) of HMC. Several literature reports describe the chemical alterations which occur during fermentation of whole corn plants and grasses and legumes, (Watson and Nash, 1960), but information concerning the fermentation of HMC is limited. The objective of this research was to determine the influence of fermentation and of moisture content of HMC at ensiling on indices of the extent of fermentation (pH, protein solubility) and nutritive value (starch availability).

Materials and Methods

Samples of corn grain were obtained from truckloads produced in the Southern High Plains upon delivery to a feedlot at Garden City, KS. Samples were the residues remaining from determination of dry matter of the delivered grain. Since individual samples were of insufficient size to subdivide and might represent only one variety or one production location, samples within moisture ranges were composited into single larger samples which represented from 10 to 20 separate loads of grain. These formed 1 kg samples at each of the following moisture levels: 21, 23, 25, 27, 29, 31, 33 and 35%. These

samples were ground in a coffee mill (Braun, Aromatic KSM2, 281 Albany St. Cambridge, Mass. 02139) and divided into sub-samples which were reconstituted with water to form each of the higher moisture levels: 25, 27.5, 30, 32.5 and 35% as illustrated in table 1.

Approximately 50 g from each initial and final moisture level were placed in duplicate 150 ml plastic bags (Whirl-Pak, NASCO. 901 Janesville Ave. Fort Atkinson, Wis.) and stored at 39 C for 60 days to permit fermentation. In addition duplicate bags of HMC without addition of water were allowed to ferment as above or were stored frozen. The effect of fermentation on chemical composition was determined with these samples. The three types of samples for subsequent discussion will be called 1) reconstituted HMC, 2) fermented (non-reconstituted) HMC and 3) frozen HMC.

Following the storage or fermentation process, sub-samples were dried for 24 h at 100 C and weighed to determine dry matter (DM) content. Total crude protein (CP) was calculated from Kjeldahl nitrogen measurement (AOAC, 1975). The pH was monitored with a combination electrode on a distilled water extract of a non-dried sub-sample. Ash content was determined by placing sub-samples in an oven at 600 C for 12 h and organic matter (OM) was calculated as DM minus ash. To determine the amount of soluble protein, sub-samples were incubated in .15 N saline at 39 C for 20 h. Samples were filtered through Whatman #4 filter paper and nitrogen content of the residue was determined by the Kjeldahl procedure (AOAC, 1975).

Starch content of sub-samples was estimated using the procedure described by MacRae and Armstrong (1968). This procedure involves gelatinizing the starch, hydrolysis of amylose and amylopectin to

glucose with glucosidase, and determination of free glucose with glucose oxidase. To estimate the amount of readily available starch, the gelatinization step of the starch analysis procedure outlined above was deleted. This would represent only the oligosaccharides readily accessible to the enzyme solution and presumably not part of starch granules.

To determine the influence of fermentation on chemical composition of HMC, compositions of fermented and frozen (non-fermented) HMC were compared. These data were statistically analyzed as a Randomized Block Design with sub-sampling, where the fermented and frozen HMC were the two treatments and the eight initial water levels were blocks. To determine the relationship of chemical composition of ensiled HMC to water content of HMC, compositions of fermented and reconstituted HMC were regressed on initial (non-reconstituted) water content, ensiling water content (inherent plus water added at the start of fermentation), and final DM content (after the fermentation period). Both reconstituted and fermented HMC were used in the regression analysis which employed the General Linear Model Procedure of the Statistical Analysis System (SAS, 1979).

Results and Discussion

Fermentation decreased pH of HMC ($P<.01$) while it increased content of soluble protein ($P<.01$) and available starch ($P<.10$) as shown in table 2 and appendix tables 1 to 5. In addition, DM and OM content of HMC decreased ($P<.01$) with fermentation (74.0 to 73.4%). These changes could be attributed to several factors. First, some workers have suggested that water is produced during fermentation.

Examination of fermentation pathways (McDonald, 1973), however, reveals that except for one minor pathway of fermentation, water is not produced during anaerobic fermentation due to lack of oxygen. Secondly, during fermentation, CO_2 is produced and is lost as a gas. This represents a loss in wet and dry weight. Energy loss during fermentation is usually much smaller than weight loss (Owens et al., 1970a; McDonald et al., 1973) as endproducts of fermentation usually are more dense energetically than substrates. Thirdly, volatile products (lactate, acetate, propionate, ethanol) are produced during fermentation. These products are lost during the heat drying process used to estimate dry matter. The decrease in DM during fermentation was only .9%, considerably lower than the suggestion that 3% of dry matter is lost during fermentation of commercially produced HMC (Gill, 1983). This difference is not surprising since commercial pit silos have a much larger exposed surface which permits greater loss of volatiles and greater penetration of oxygen which would increase oxidative loss of dry matter and energy. Fermentation in the plastic bags in this trial would most closely simulate fermentation which occurs in the anaerobic center of a large mass of ensiled HMC and would not include surface oxidative losses.

The pH, soluble protein percentage, starch and OM content of fermented HMC were found to be related the DM content of HMC after ensiling. These variables had little relationship with initial (inherent or harvest) moisture content ($P>.10$). This suggests that final composition of fermented HMC did not differ with source of moisture (inherent or added) in HMC. Consequently, when harvest at a high moisture content is not possible, addition of water at ensiling

time may result in fermentation which chemically resembles fermentation of grain harvested at the higher moisture content. For simplicity of discussion, changes below will consider the effect of adding moisture which corresponds to decreasing DM of HMC.

The pH of fermented HMC increased ($P<.01$) as DM of HMC increased (figure 1). For every 1% increase in DM, pH of the fermented product increased by .065 units. This probably is a result of increased production of lactic acid and other organic acids during fermentation (Klosterman et al., 1960; Thornton et al., 1977a) and would reflect an increase in the extent of microbial action. It is generally believed that un-ionized lactic acid is the component which halts microbial fermentation. Moisture in grain will dilute the lactic acid and permit fermentation to continue until more lactic acid is produced and pH is lower. Goodrich et al. (1975) also observed that pH values of ensiled HMC increased (from 4.8 to 5.9) as the dry matter content of HMC increased from 66.5 to 69.5 percent.

Crude protein content was not influenced by moisture content of HMC, but soluble protein, expressed as percent of the total crude protein, increased ($P<.01$) as DM decreased (figure 2). For every 1% increase in DM, the percentage of soluble protein decreased by 1.9%. The solubility of protein or N typically is greater with fermented than fresh feeds and forages. With whole plant corn material, this change occurs within hours after harvest and is presumably due to increased action of proteolytic enzymes from the plant (Bergen, 1974; 1976). But with HMC, solubilization continues for at least a month following harvest (Prigge et al., 1976a). Consequently, protein solubilization in HMC may be due to bacterial enzyme action or to

fermentation acids. Since protein may encapsulate starch granules and is the glue which holds starch granules together, solubilization of protein may increase the exposure of starch (Florence et al., 1968; Sullins et al., 1971) which may increase digestion of starch by animals.

One unexpected finding in this study was the decrease in starch percentage ($P<.01$) as DM increased (figure 3). Presumably, starch content should not change with moisture level. Only a small low portion of the variation ($r^2=.19$), however, was explained by DM content. Linear regression would suggest that for a 1% increase in DM, starch decreased by .47%, so that an increase in DM from 65 to 80% would decrease starch content by 7%. Examination of means suggests that the highest starch content was for grain at the intermediate levels of moisture (table 3) and that the relationship may be curvilinear, not simply linear.

Loss of dry matter during fermentation could explain a small portion of the increase in starch, but carbohydrate would be expected to disappear during fermentation. Bacteria can synthesize carbohydrates, and carbohydrates are always present at low concentrations in microorganisms (Jouany and Thivend, 1972b; Metzler, 1977; Stryer, 1981). During fermentation, catabolism rather than synthesis of carbohydrates would be expected. The most logical explanation for the change in starch content is that the analytical procedure for starch (total oligosaccharides) fails to detect some of the carbohydrate present in grain higher in DM. Possibly the autoclaving process fails to gelatinize all the starch or the amyloglucosidase fails to cleave the all the glucosan present in drier

grain. Liberation of starch from an indigestible, non-assayable form may explain some of the nutritional benefit reported in energy availability (Hale, 1980) from fermentation of corn grain.

Available starch, expressed as percent of total starch, increased ($P<.01$) as percent water in the fermented grain increased (figure 4). This presumably reflects liberation of starch from starch granules during the fermentation process. If starch can be hydrolyzed to glucose without gelatinization, it should be rapidly attacked and fermented by microbes in the rumen.

In conclusion, the extent of fermentation, as measured by products of fermentation, appeared to be directly proportional to the amount of moisture present during fermentation. This relationship may not exist outside the range of moisture levels tested, however, as Danley and Vetter (1974b) found no consistent effect of moisture content on fermentation of corn. They used only low (16, 18 and 22%) moisture levels, however, and changes noted in this trial parallel results from a field survey of fermented HMC by Thornton et al. (1977a).

TABLE 1. DISTRIBUTION OF THE DIFFERENT FINAL MOISTURE LEVELS

Inherent water,%	Moisture after Reconstitution, %[a]				
	25	27.5	30	32.5	35
21	X	X	X	X	X
23	X	X	X	X	X
25		X	X	X	X
27			X	X	X
29			X	X	X
30				X	X
33					X
35					

[a] X represents a moisture level after reconstitution.

TABLE 2. EFFECT OF FERMENTATION ON CHEMICAL COMPOSITION OF HMC

Item	Treatment		SE
	Frozen	Fermented	
DM, %	74.0[a]	73.4[b]	.15
OM, %	73.1[a]	72.5[b]	.16
pH	6.2[a]	4.9[b]	.10
Protein, %			
Total, % of DM	9.1[b]	9.2[a]	.15
Soluble, % of total	25.7[b]	35.9[a]	1.80
Starch,			
Total, % of DM	75.9[c]	75.7[c]	.12
Available, % of total	41.6[c]	46.6[c]	1.82

[a,b] Means in a row with different superscripts differ (P<.01).
[c,d] Means in a row with different superscripts differ (P<.10).

TABLE 3. CHEMICAL COMPOSITION OF UNFERMENTED CORN

Item	Moisture Level, %							
	21	23	25	27	29	31	33	35
DM, %	77.3	73.4	72.8	73.9	72.2	72.1	72.5	72.3
OM, %	76.4	72.8	72.1	72.8	71.4	71.2	71.5	71.5
pH	5.3	5.2	5.1	5.1	4.8	4.7	5.1	4.9
Protein, %								
Total, % of DM	9.8	9.2	9.7	9.3	8.5	8.7	9.1	9.4
Soluble, % of total	26.0	35.0	27.7	35.2	41.0	43.1	30.6	42.5
Starch, %								
Total, % of DM	70.3	68.2	78.7	80.7	78.5	78.9	74.9	74.5
Available, % of total	40.5	45.2	49.0	44.0	46.8	51.0	45.8	48.6

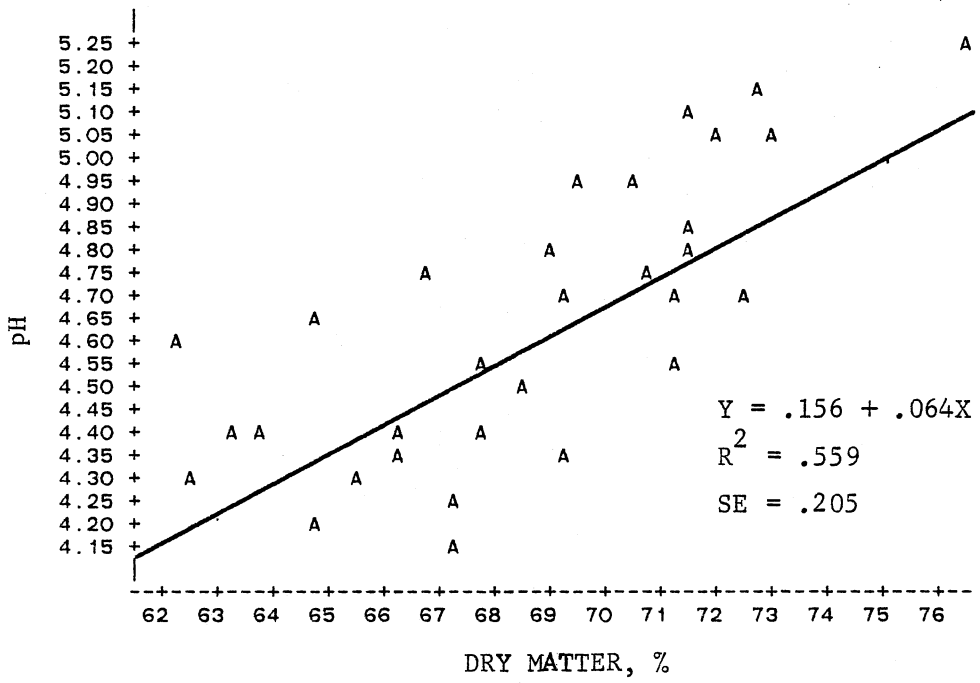


Figure 1. Relationship Between pH and Dry Matter of Fermented High Moisture Corn

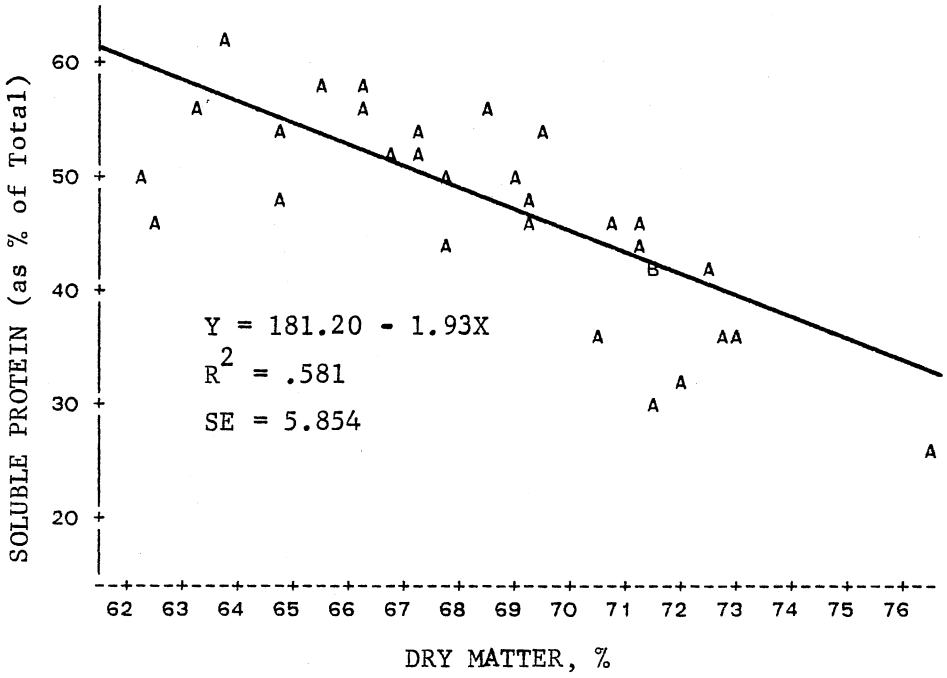


Figure 2. Relationship Between Soluble Protein as Percent of Total Protein and Dry Matter of Fermented High Moisture Corn

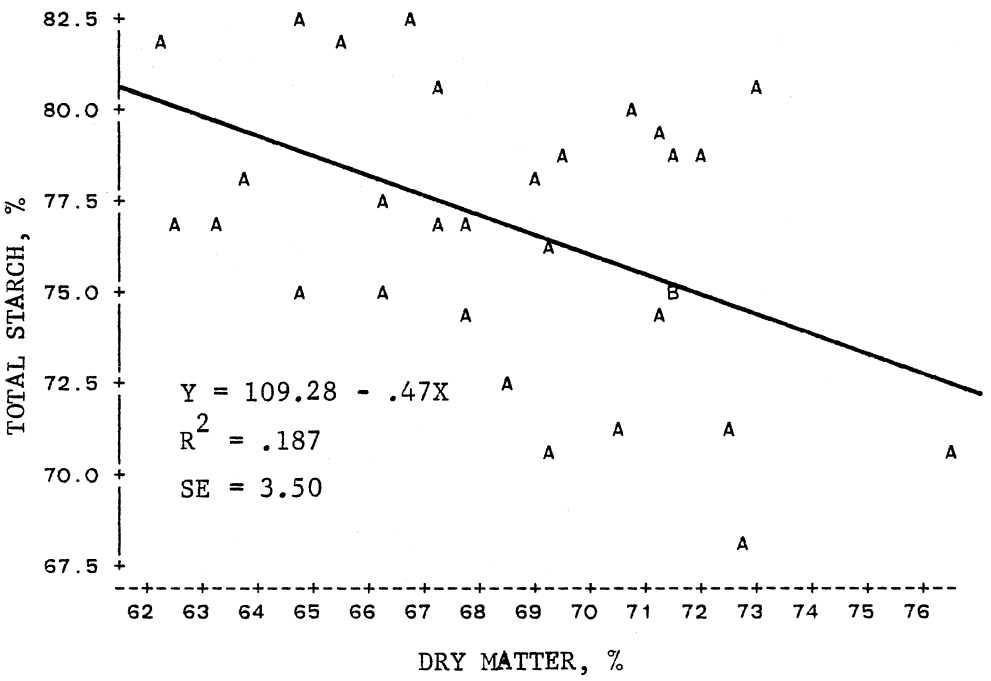


Figure 3. Relationship Between Total Starch and Dry Matter of Fermented High Moisture Corn

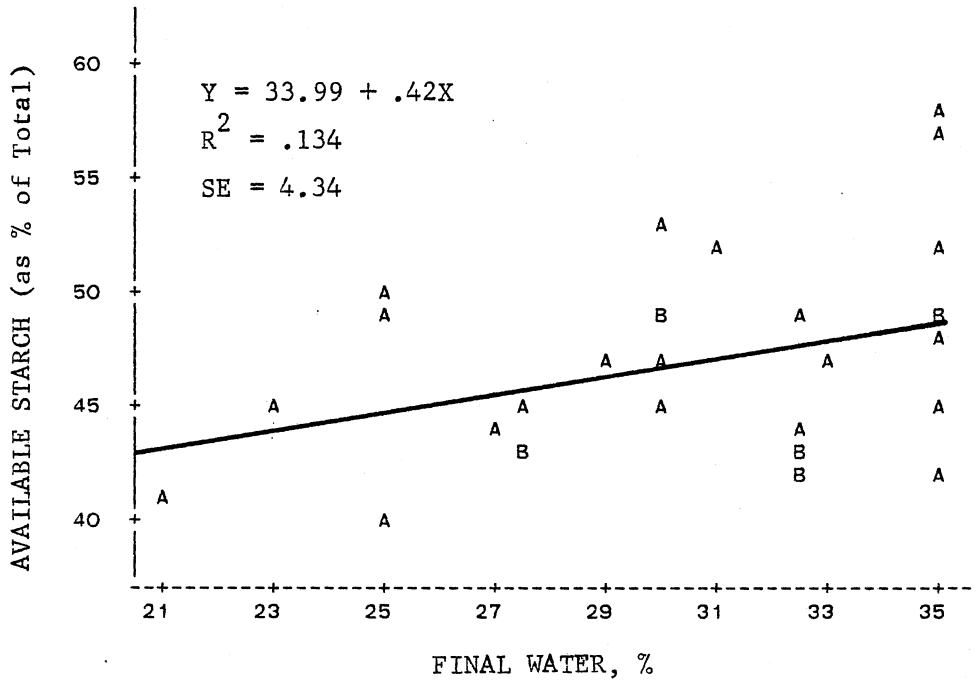


Figure 4. Relationship Between Available Starch (as % of Total) and Final Water Content

CHAPTER IV

EFFECT OF MOISTURE LEVEL AND FERMENTATION ON DIGESTIBILITY OF HIGH MOISTURE CORN AND PERFORMANCE OF LAMBS

Summary

The effects of fermentation and moisture level of ground corn grain on digestibility and performance of growing lambs was studied in two trials. In both trials, ground corn grain was reconstituted with water to levels of 20, 25, 30, 35 and 40 percent moisture and allowed to ferment for 60 days in plastic bags prior to feeding. In addition, for five additional treatments, water was added to ground corn at feeding time to produce grain containing similar levels of moisture. In experiment 1, 59 wethers (35 kg) in individual pens were fed diets consisting of each of these types of grain at 80% of diet dry matter plus a urea-cottonseed hull supplement for 21 days. Moisture content did not significantly alter daily dry matter (DM) intake, but average daily gain and efficiency of feed use decreased ($P<.05$) as moisture level increased. Feed intake, daily gain and efficiency of feed use all favored ($P<.05$) fermented material over grain wetted at feeding time. In experiment 2, digestibility of these diets was determined with 30 lambs fitted with bags for collection of feces. Digestibilities of DM, organic matter (OM) and protein were not affected by addition of water to corn, but starch digestibility increased ($P<.01$) and digestibility of acid detergent fiber (ADF)

declined ($P<.05$) with added moisture. The fermentation process decreased digestibilities of DM, OM and ADF ($P<.01$), but did not alter digestibilities of starch and protein. The improved feed efficiency with fermentation in this experiment cannot be explained by an increase in digestibility of nutrients. Other effects of fermentation, such as a change in the site of digestion, may explain the greater utilization of reconstituted corn grain.

Introduction

The fermentation process modifies the nutrient characteristics of the HMC grain. Effects of reconstitution or fermentation on nutritive value of feeds are generally studied by comparison with a dry corn control. Hence, moisture level of the diet and fermentation are generally confounded and cannot be separated statistically.

Water content of feeds alone may affect rate of eating, saliva production, ruminal distention, rate of ruminal digestion and rate of passage (Matsushima, 1979). In addition, fermentation modifies physical and chemical characteristics which may alter animal performance. For example, feed intakes of fermented feeds are often lower following fermentation. This has been attributed to levels of soluble nitrogen and organic acids produced during fermentation (McLeod et al., 1970; Wilkinson et al., 1976) though this conclusion has been challenged by others (Bergen et al., 1974; Phillip et al., 1980).

Similarly, the improved efficiency of feed use with fermented feeds has been attributed by some workers to higher levels of organic acids produced during ensiling (Klosterman et al., 1960; Henderson and

Bergen, 1970) while others have suggested that errors in dry matter determination and increases in digestibility are partially responsible (Goodrich and Meiske, 1971).

The objectives of these trials were to evaluate independently the effects of fermentation and of moisture content on performance of growing lambs and digestibility of corn grain.

Materials and Methods

Corn for both trials was prepared at five different moisture levels either with or without fermentation. All corn grain was ground through a 6 mm screen and water was added to obtain five different levels of moisture (20, 25, 30, 35 and 40%). The non-fermented grain was reconstituted at feeding time. For fermentation, to simulate conditions in a silo, reconstituted grain was packed in double lined plastic bags which were compressed by evacuation of gas with a vacuum pump, sealed and held at 39 C for 60 days prior to feeding. Chemical composition of the fermented and wetted grains are presented in table 1.

Trial 1

Fifty-nine wether lambs (35 kg) were allocated to individual pens. Lambs were fed individually once daily at 1500 h. Feed intakes and weight gains were measured during a 21 day feeding period following a 7 d adaptation period. Diet dry matter (table 2) consisted of 80% corn grain and 20% supplement. The supplement provided cottonseed hulls as a source of roughage, urea as a source of non-protein nitrogen, minerals and vitamins A and D.

Trial 2

To determine the effect of moisture content and fermentation of HMC on digestibility of DM, OM, starch, protein and acid detergent fiber (ADF), thirty of the lambs from trial 1 were used. Animals were fed once daily at 1500 h at a level equal to 90% of ad libitum intake during a 14 d adaptation period. Diets were identical to those used in trial 1. Chromic oxide was included as an indigestible marker if total collection of feces had proved infeasible. All lambs were harnessed with bags for collection of feces and total fecal output was collected for 6 days. Feed, orts and fecal samples were analyzed for DM (100 C for 24 h), ash (600 C for 12 h), Kjeldahl nitrogen (AOAC, 1975), starch (MacRae and Armstrong, 1968) and ADF (Goering and Van Soest, 1970).

Data from both trials were statistically analyzed using the General Linear Model Procedure of SAS (SAS, 1979) for a completely randomized design (Steel and Torrie, 1980) with a factorial structure. The two factors were time of moisture addition (fermented versus corn wetted at feeding time) and reconstitution moisture level (20, 25, 30, 35, and 40%). Only when the interaction between factors was non-significant ($P>.10$) were main effects discussed. Means were compared using Duncan's multiple range testand by single degree of freedom contrasts for linear, quadratic, cubic and quartic effects of moisture level.

Results and Discussion

Trial 1

Where no interaction of moisture level and time of moisture

addition was apparent (P>.10), main effects will be discussed. Animal performance results are summarized in table 3 and appendix tables 6 to 8. Daily DM intake was not affected (P>.05) by moisture addition and no interaction was apparent (figure 1). But average daily gain decreased (P<.05) as moisture level increased, however a significant interaction (P<.01) between the linear effect of moisture and fermentation was apparent. As moisture level increased, daily gain decreased when water was added at feeding time while with fermented corn, daily gain was no altered by moisture level as illustrated in figure 2. Efficiency of feed utilization decreased (P<.05) as water level increased but again an interaction was apparent as shown in figure 3. Efficiency was depressed by adding water at feeding time while efficiency with fermented corn was relatively constant across moisture levels.

Several explanations are possible. First, added water would reduce chewing time, saliva production and ruminal buffering. This may have predisposed animals to acidosis which would depress animal performance. Secondly, added water would permit growth of molds and yeasts (Jones et al., 1974) whose by-products may affect animal production. However, addition of water or molasses to diets at feeding time may prove useful to reduce dustiness and thereby both to increase feed intake and to reduce losses due to wind. Matsushima (1979) added water to steer diets at feeding time. Added water did not affect DM intake though water intake declined. Daily gains and feed efficiency tended to favor cattle fed the wetted diets.

Fermentation increased DM intake, average daily gain and

efficiency of feed utilization ($P<.05$) by 11.3, 16.7 and 14.8%, respectively (table 4). Similar results have been observed by others (Thornton et al., 1979; Gill et al., 1982) though DM intake has not always increased with fermentation (Bergen et al., 1974; Phillip and Buchanan-Smith, 1982).

Dry matter intake (figure 1) was greater with fermented than wetted grain at all moisture levels. Feed boxes were cleaned every day to keep feed fresh. Nevertheless, wetted feed tended to heat in the feed box and a moldy odor could be detected occasionally. This might explain the lower DM intake for grain wetted at feeding time. Average daily gain (figure 2) was greater with fermented than wetted grain at all moisture levels above 20% while feed efficiencies (figure 3) favored fermented over wetted grain at moisture levels above 25%.

The influence of moisture level on feed intake of HMC has been examined in only a few trials. Early reports suggested that feed intake was very low for corn and milo containing over 30% moisture (Sprague and Breniman, 1969; White and Totusek, 1969). No such depression was apparent in this study. Higher feed intake and lower efficiency of utilization was noted with corn at 24 than at 15 and 30% moisture by Teeter et al. (1979). In our trial, intake was lowest at 30% moisture.

Several explanations for the reduction in feed intake with higher moisture levels in HMC have been proposed. All involve formation of fermentation by-products which reduce feed intake. First, at higher moisture levels, ethanol is produced at levels up to 2% of dry matter (Goodrich et al., 1975). Intoxication will reduce intake and animal performance. Secondly, nitrogen-containing compounds are formed

during fermentation with the decarboxylation of amino acids (Wrenn et al., 1963; Neumark et al., 1964). Of special concern are amines which have pharmacological effects. Neumark and Tadmor (1968) reported that the pattern of feed intake is altered by infusion of histamine in association with acids, but intra-ruminal infusion of histamine alone did not affect DM intake (McDonald et al., 1963). High concentration of free acids also can depress DM intake. Partial neutralization with sodium bicarbonate before feeding has increased the intake of well preserved grass and corn silages as well as wet brewers products (McLeod et al., 1970) and intake of fermented material is reduced by addition of lactic acid (McLeod et al., 1970). Compared with fermented forages, which may contain up to 10% of their dry weight as lactic acid, the acid load from fermented grains at 1 to 3% of dry matter (Goodrich et al., 1975) appears small.

Trial 2

Digestibilities of DM, OM and crude protein were not affected by the water level (table 5; Appendix tables 9 to 12), but starch digestibility increased as water content increased ($P<.01$). This change may be due to swelling of the starch granule (Sullins et al., 1971) which opens the granule for enzymatic attack. In addition, the protein matrix is softened by water which may increase susceptibility to enzymatic attack. Despite the higher solubility of protein of the fermented grain containing higher moisture levels, moisture level had no significant effect on protein digestibility in this experiment. Another explanation would be that amylolytic enzymes or microbes in the rumen are more active at a more acid pH.

Acid detergent fiber digestibility was lower with wetter material ($P<.05$). This drop in fiber digestion is presumably due to a reduced ruminal pH. A pH below 6 considerably decreases cellulolytic activity (Hungate, 1966; Van Soest, 1980). Such a decrease in ruminal pH would be expected from greater digestibility and production of acids from starch (Dunlop, 1970) and to less salivary buffering of ruminal contents.

The influence of fermentation on digestibility is presented in table 6. DM and OM were less digestible with fermented than wetted corn. This is partly due to lower digestibility of ADF. Previous studies using in situ measurements (Galyean et al., 1977) and in vivo trials with beef cattle (Galyean et al., 1975; Rust et al., 1979; Teeter et al., 1979) have shown that dry matter from fermented corn grain is more digestible than dry matter from dry grain. However, a species difference may exist, since Buchanan-Smith and Yao (1978) found that digestibility of DM and energy were lower with fermented than non-fermented whole corn plant silage. Lambs chew their feed more thoroughly than cattle. One of the benefits of fermentation may be due to increased susceptibility of particles to microbial and enzymatic attack. Thorough chewing of grain to reduce particle size may remove a portion of this benefit.

Results of these two trial are difficult to amalgamate. Without a change in digestibility with fermentation, the increase in efficiency of feed use in the feeding study is difficult to explain. In addition a change in extent of digestion, a change in site of digestion can influence nutritive value of a feed. Shifting the site of digestion from the large intestine to the rumen could increase

efficiency of energy use considerably. The following chapter addresses the effect of moisture level on site of digestion.

TABLE 1. CHEMICAL COMPOSITION OF WETTED AND FERMENTED CORN GRAIN

Type[a]	Moisture content, %									
	20		25		30		35		40	
	W	F	W	F	W	F	W	F	W	F
Dry matter, %	78.0	79.2	74.7	73.5	68.3	69.4	63.6	64.4	58.7	58.7
Protein										
Total, % of DM	9.2	10.4	9.4	10.3	9.4	9.7	9.4	10.7	9.8	10.2
Soluble, % of total	7.9	9.6	8.1	10.4	9.4	11.5	9.4	30.0	6.4	43.4
Starch, % of DM	74.2	67.8	72.7	67.1	73.4	78.1	76.1	77.2	72.9	75.1
Ash, % of DM	1.5	1.7	1.5	1.6	1.6	1.6	1.5	1.6	1.3	1.7
ADF, % of DM	3.9	6.0	3.7	5.4	2.8	4.2	3.2	3.2	2.9	2.7

[a] W represents corn which had water added immediately prior to feeding while F had water added prior to a 60 day fermentation interval.

TABLE 2. DIET COMPOSITION

Ingredient	Percent of DM[a]
Corn, dent yellow, ground (IFN 4-02-931)	80.0
Supplement:	
Cottonseed hulls (IFN 1-01-599)	15.25
Molasses (IFN 4-04-696)	1.69
Urea	.92
Limestone (IFN 6-02-632)	.76
Salt, trace mineralized[b]	.46
Chromic oxide	.46
Dicalcium phosphate (IFN 6-01-080)	.23
Ammonium chloride	.23

[a] Vitamin A and D added. (A=30,000 USP/g; D=15,000 IU/g).
[b] Morton Salt Co., Chicago, IL. 60606.

TABLE 3. GRAIN MOISTURE CONTENT AND LAMB PERFORMANCE

Item	Moisture Content, %					
	20	25	30	35	40	SE
DM intake, kg/day	1.22	1.22	1.12	1.19	1.20	.04
Average daily gain, kg	.22[a]	.21[ab]	.17[c]	.18[bc]	.17[c]	.17
Feed/Gain	5.74[b]	5.92[b]	7.07[ab]	7.51[a]	7.44[a]	.49

[a,b,c] Means in a row with different superscript differ ($P<.05$).

TABLE 4. FERMENTATION AND LAMB PERFORMANCE

Item	Fermented	Non-fermented	SE
DM intake, kg/day	1.25[a]	1.15[b]	.03
Average daily gain, kg	.21[a]	.18[b]	.01
Feed/Gain	6.22[c]	7.14[d]	.44

[a,b] Means in a row with different superscript differ (P<.01).
[c,d] Means in a row with different superscript differ (P<.05).

TABLE 5. GRAIN MOISTURE CONTENT AND DIGESTIBILITY

Digestibility, %	Moisture Content, %					
	20	25	30	35	40	SE
Dry Matter	73.0	73.1	74.4	75.1	73.7	1.13
Organic Matter	74.2$_{c}$	74.5$_{c}$	75.7$_{bc}$	76.3$_{ab}$	75.0$_{a}$	1.13
Starch	95.5^{c}	97.7^{c}	98.2^{bc}	99.1^{ab}	99.2^{a}	.92
Protein	66.8$_{a}$	64.8$_{b}$	63.4$_{b}$	64.9$_{b}$	64.6$_{b}$	1.25
Acid Detergent Fiber	31.9^{a}	24.5^{b}	26.6^{b}	24.8^{b}	23.8^{b}	.02

^{a,b,c} Means in a row with different superscript differ ($P<.05$).

TABLE 6. FERMENTATION OF CORN GRAIN AND DIGESTIBILITY

Digestibility	Wetted	Fermented	SE
Dry Matter	75.3[b]	72.4[a]	.71
Organic Matter	76.7[b]	73.6[a]	.71
Starch	98.3	98.4	.58
Protein	65.2	64.7	.79
Acid Detergent Fiber	29.1[b]	23.6[b]	.01

[a,b] Means in a row with different superscript differ (P<.01).
[c,d] Means in a row with different superscript differ (P<.05).

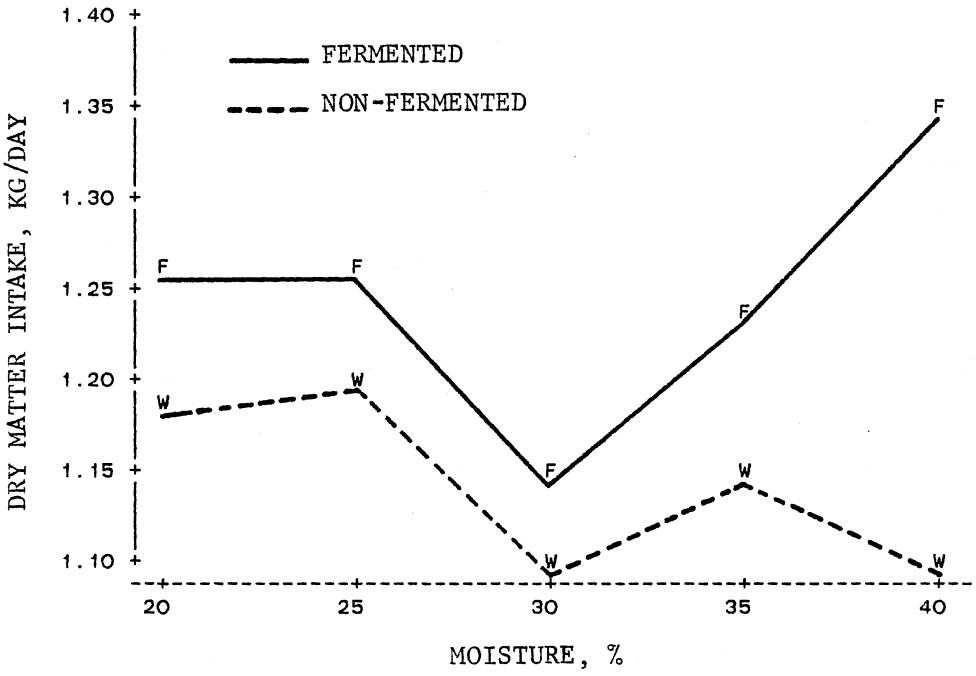


Figure 1. Effect of Water Level on Dry Matter Intake by Lambs Fed Fermented and Non-fermented High Moisture Corn

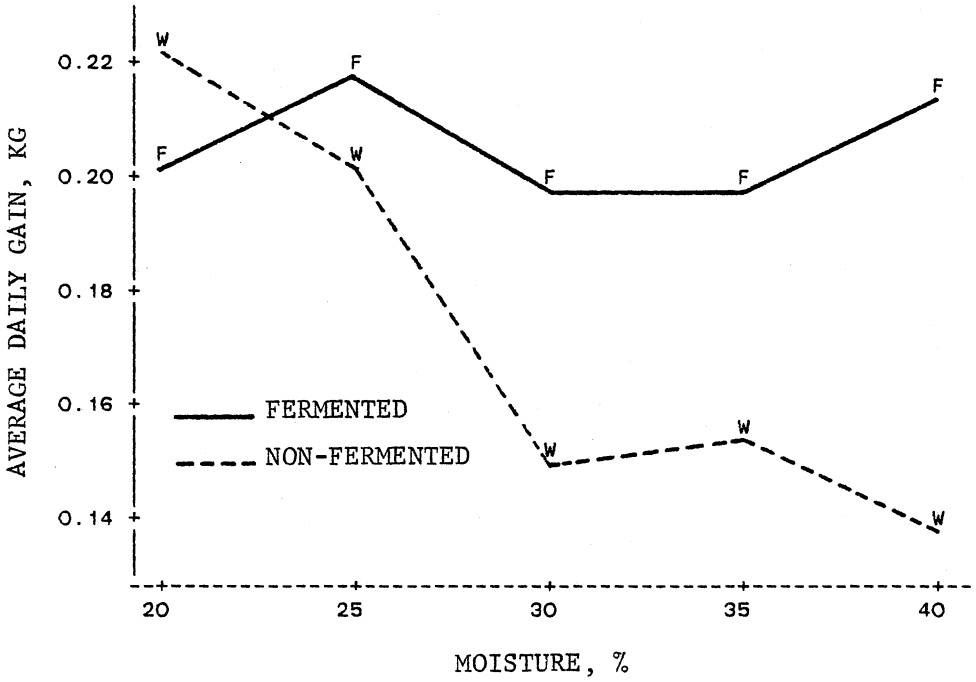


Figure 2. Effect of Water Level on Average Daily Gain by Lambs Fed Fermented and Non-fermented High Moisture Corn

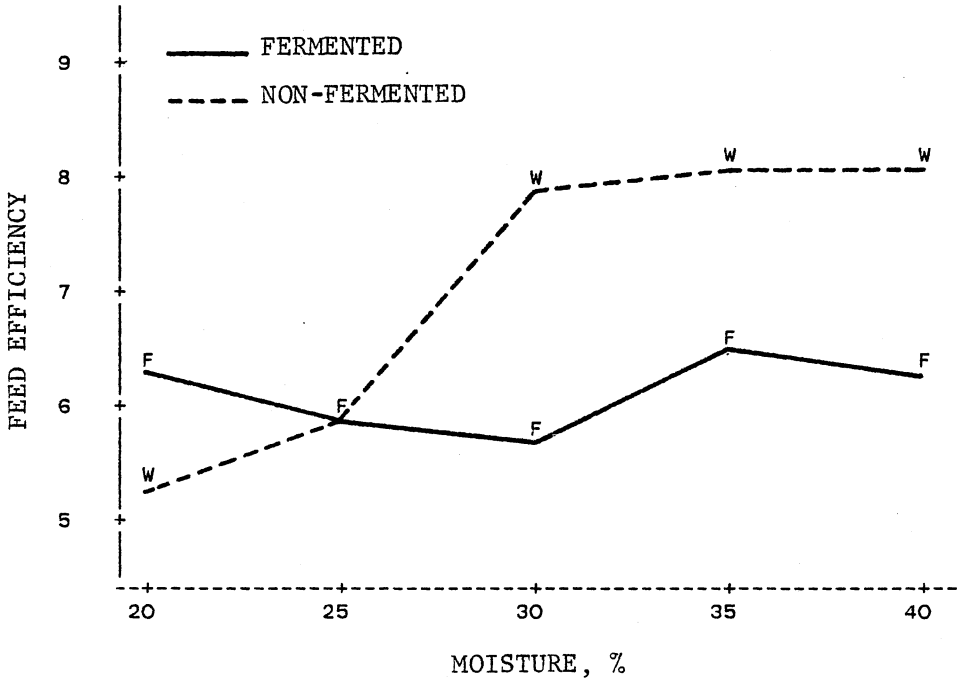


Figure 3. Effect of Water Level on Feed Efficiency by Lambs Fed Fermented and Non-fermented High Moisture Corn

CHAPTER V

INFLUENCE OF MOISTURE LEVEL ON SITE OF DIGESTION OF FERMENTED HIGH MOISTURE CORN GRAIN BY STEERS

Summary

Ground corn was reconstituted to five different levels of moisture (15, 20 25, 30, 35 percent) and fermented for 45 days. Site and extent of digestion was measured with five 530 kg steers equipped with ruminal, duodenal and ileal cannulated steers in a latin square experiment. Starch digestibility in the rumen, small intestine and total tract increased linearly ($P<.05$) with moisture level. Added moisture shifted site of digestion from the intestines to the rumen. Duodenal N flow, efficiency of microbial growth and escape of fed protein from the rumen were quadratically related ($P<.05$; $P<.01$; $P<.10$) to moisture level with peaks at 25% moisture. Ruminal and total tract digestion of acid detergent fiber (ADF) decreased ($P<.05$) with level of moisture added. Results indicate that both site and extent of digestion of nutrients from HMC are altered by moisture content of the corn grain.

Introduction

Fermented early harvested corn grain (HMC) has a greater feeding value than dry whole or rolled grain for beef cattle (Hale, 1980). This difference may be due to pre-digestion of nutrients during

fermentation which makes nutrients more available to ruminant animals. The physical changes of swelling and reduction in particle size will facilitate microbial and enzymatic attack. Total tract digestibility of OM and starch often is greater for corn fed in the high moisture form than corn fed dry (Rust et al., 1981) although the value of HMC as measured by feed efficiency and digestibility appears to vary with moisture content of HMC (Galyean et al., 1976; Teeter et al., 1979). Extent of ruminal digestion of dry matter and starch appears greater with HMC than with dry corn (McKnight et al., 1971; Galyean et al., 1975) though the influence of moisture level on extent of ruminal and intestinal digestion of HMC has not been studied. The objective of this research was to determine the effect of moisture level in reconstituted corn on site and extent of digestion of nutrients from HMC by steers.

Materials and Methods

Five steers (530 kg) were fitted with permanent ruminal, duodenal and ileal cannulas and fed corn reconstituted to five levels of moisture (15, 20, 25, 30 and 35%) in a latin square experiment. Reconstituted rather than high moisture harvested HMC was used to reduce labor and to reduce variation in nutrient content of the starting material. To produce reconstituted corn, corn grain ground through a 6 mm screen was wetted, mixed, and packed in double lined plastic bags which held about 35 kg. Bags were compressed by evacuating gas with a vacuum pump, sealed and stored at 39 C for 45 d for fermentation. Chemical composition of the fermented grains is presented in table 1.

Diet dry matter consisted of 80% fermented corn and 20% supplement (table 2) which was balanced to provide protein, minerals and vitamin A to meet nutritional requirements of those steers (NRC, 1976). Chromic oxide was included in the supplement as an indigestible marker. Dry matter intake was restricted to 1.8% of body weight to avoid digestive upsets and feed refusals. During the fifth period, the steer fed the 20% moisture level became ill and would not eat. Data from that animal in that period were removed prior to statistical analysis.

Steers were housed in individual pens with concrete slatted floors and fed twice per day (0800 and 2000 h). Orts were removed, weighed and samples every day. The first seven days of each 10 day periods was used for adaptation to the new moisture level. Ruminal, duodenal, ileal and fecal samples were collected in the morning and afternoon of the final three days of each period.

Immediately after being obtained, digesta samples were frozen. At the end of each period, digesta samples from each sampling site of the digestive tract were composited. This composite was divided into two equal portions with a dividing funnel to maintain the ratio of solids to liquid. One portion was frozen and the other was dried at 60 C for four days, ground and chemically analyzed.

Feed, duodenal, ileal and fecal samples were analyzed for DM (105 C for 24 h), ash (600 C for 12 h), crude protein by the Kjeldahl nitrogen procedure (AOAC, 1975), starch (MacRae and Armstrong, 1968), chromium (Fenton and Fenton, 1979) and ADF (Goering and Van Soest, 1970). Duodenal samples also were analyzed for nucleic acids by the procedure of Zinn and Owens (1982). Rumen samples were analyzed for

ammonia by the micro-ammonia procedure of Chaney and Marbach (1962). The pH values for composited samples were determined with a combination electrode after thawing of ruminal samples and after re-wetting duodenal, ileal and fecal samples. Bicarbonate would be lost during freezing. Hence, bicarbonate buffering would have been lost prior to pH measurement and values should not be compared with pH determined with fresh samples.

Statistical analysis was conducted using the General Linear Model procedure of the SAS system (SAS, 1979) for a 5 x 5 latin square design (Steel and Torrie, 1980). Means were compared by Duncan's multiple range test protected by a significant F test and by single degree of freedom contrasts for linear, quadratic, cubic and quartic effects of moisture level.

Results and Discussion

Digestibility of dry matter (DM) in the rumen was quadratically related ($P<.01$) to moisture level with the lowest digestibility at 25% moisture (table 3; Appendix table 13). In the the total tract, digestibility of DM was greater with 35% moisture than for 30% moisture HMC (82 vs 76 %). Digestibility of organic matter (OM) followed a similar pattern (table 4; Appendix tables 14 to 16). Since a portion of the OM leaving the rumen consists of microbial cells and is not undigested feed, OM passage was adjusted for presence of microbial OM to estimate true OM digestion. True OM digestion was similar at the three lower moisture levels but increased slightly at 30% moisture and increased markedly at 35% moisture.

Digestibility of starch entering each segment of the digestive tract increased linearly ($P<.01$) with moisture level in the rumen, small intestine, and total tract (table 5; Appendix tables 17 to 19). This indicates that moisture addition increased availability at all sites. This suggests that factors limiting starch digestion in the rumen and intestine responded similarly to moisture level and therefore may be similar.

Despite the increase in digestion at all sites, site of digestion was shifted by moisture level. The increase in ruminal digestion decreased the flow of residual starch to the small intestine. Hence, added moisture shifted site of digestion forward to the rumen and away from the intestines. The primary site of starch digestion was the rumen. These findings demonstrate that processing can alter extent of starch digestion in the rumen independent of level of feed intake as suggested previously by Karr et al. (1966). An increase in level of feed intake, in contrast, may shift site of starch digestion away from the rumen toward the small intestine.

Extent of ruminal starch digestion was inversely related to ruminal pH (table 9). Though cause and effect cannot be determined from this study, acids produced from digestion of starch will lower pH. In addition, with more moisture in the feed, saliva input of liquid and buffers may decrease which would allow ruminal pH to fall.

Shifting site of digestion of energy from the intestines to the rumen can alter both protein and energy status. First, an increase in the extent of ruminal digestion will provide more energy for microbial growth. This will increase the flow of protein to the small intestine. An increase microbial protein synthesis in the rumen also

will increase the amount of dietary or recycled non-protein nitrogen which can be used. Secondly, up to 30% of the energy from the substrate fermented is incorporated into the microbial mass. With fermentation in the rumen, this microbial mass is passed to the small intestine for digestion and absorption. In contrast, the microbial mass formed in the large intestine is not subjected to extensive digestion but would be largely lost in feces. Hence, fermentation in the large intestine is relatively inefficient. Finally, fermentation in the rumen will lower ruminal pH. A lower ruminal pH will reduce absorption of ammonia (Bloomfield et al., 1963) which will extend the time period for ammonia utilization by ruminal bacteria and also will reduce the energy expended by the liver to synthesize recycled ammonia.

Duodenal flow of N, as well as flow of its two components, dietary protein escaping ruminal digestion and microbial protein, responded quadratically ($P<.05$; $P<.01$; $P<.10$) to moisture level, being highest with 25% moisture HMC (table 6; Appendix tables 20 to 22).

An inverse relationship between duodenal flow and ruminal NH_3-N was apparent. This may be a result of greater use of ammonia by ruminal microbes, greater accumulation in the rumen due to a low pH and low absorption, or to reduced ruminal digestion of dietary protein. Ruminal ammonia levels in this trial exceed the 3 mg/dl found adequate to maximize efficiency of microbial protein synthesis with a high concentrate diet (Weakley, 1983) though higher levels have been suggested by others (Okarie et al., 1977; Kang-Meznarich and Broderick, 1980) to increase total protein production by microbes and may increase extent of digestion in the rumen.

Passage of N to the duodenum exceeded N intake only with the 25% and 30% moisture HMC. This diet provided 12% protein which would exceed the level of protein used commercially with HMC diets. These results suggest that higher levels of non-protein N are needed and can be used for HMC at intermediate than at higher and lower moisture levels. Previously, Prigge et al. (1976b) suggested that more NPN can be used with HMC than dry corn diets.

Bypass of dietary protein did not respond to moisture level as expected. Most dietary protein which is soluble in water is rapidly attacked and hydrolyzed by ruminal microbes. Since protein is solubilized during the fermentation process, lower protein bypass for fermented grain would be expected. Possibly, the nitrogen solubilized during fermentation process is the same fraction which normally is attacked and digested in the rumen. Alternatively, some of the soluble protein from HMC may be escaping digestion in the rumen and passing to the small intestine.

Microbial efficiency, expressed as grams of bacterial nitrogen per kg of OM truly digested in the rumen, was quartically ($P<.01$) altered by moisture level, being highest at 25% moisture, intermediate at 30 and 35% and lowest with 15 and 20% moisture (table 6; appendix table 22). Dilution rate of ruminal microbes is one of the most important variables which affects efficiency of microbial growth in the rumen (Harrison et al., 1975; Cole et al., 1976b; Van Soest, 1982). Dilution rates of liquids and solids from the rumen were not measured in this trial, but with wetter grain and smaller particle size, dilution rates are often greater (Galyean., 1977). Microbial efficiencies in this experiments are similar to those reported by

Weakley (1983) (13 MN/kg of OM truly digested in the rumen) with high roughage diets but are lower than the values of 27-38 g of MN/kg OM reported by Sutton et al., (1975) with high concentrate diets.

ADF concentration in the diet (table 7; Appendix tables 23 and 24) tended to decrease with addition of moisture to the diet. This may be due to digestion of fiber during the fermentation. However it is generally believed that only more soluble components are degraded during silage fermentation. Digestibility of ADF in the rumen and total tract declined ($P<.05$; $P<.01$) with addition of water to HMC (table 7). This may be due to the reduction in ruminal pH (table 9). Microorganisms digesting fiber do not survive in low pH environments (Dunlop, 1970).

Rust (1983) with whole shelled corn diets containing 10% cottonseed hulls reported ADF digestibilities similar to values in this study. He suggested that fibrous cell walls of corn kernels inhibit microbial and enzymatic attack. To reduce this interference, processing is helpful. Grinding will reduce the particle size, increase surface area, and increase the rate of digestion (Galyean et al., 1977). In addition, wetting or fermentation will soften particles and increase the efficiency of mastication and exposure of grain particles to microbial enzymes. Hence, a decrease in fiber digestion may not reduce digestion of HMC as drastically as it may reduce digestion of dry corn grain. The interaction between starch and fiber digestion as it is influenced by roughage type, roughage level and grain processing needs further study.

Ruminal ash digestibilities were negative (table 8; Appendix table 25). This reflects input of minerals with saliva. Flow of ash to the duodenum tended to parallel microbial efficiency.

Both could be related to input of salivary fluid. In the total tract, addition of water at low levels decreased and at higher levels increased ash digestibility. White et al. (1973) also observed that ash digestibility was lower for HMC than dry corn. Differences may relate to altered pH of the gut and altered solubility of minerals.

TABLE 1. CHEMICAL COMPOSITION OF FERMENTED CORN

Nutrient	Moisture Content, %				
	15	20	25	30	35
Dry Matter, %	85.1	79.9	74.6	68.5	63.3
Protein					
Total, % of DM	9.9	10.4	9.5	9.2	9.8
Soluble, % of total	4.1	7.8	11.5	36.1	44.9
Starch, % of DM	67.8	67.1	78.1	77.2	75.1
Ash, % of DM	2.2	2.6	2.2	1.8	1.9
ADF, % of DM	6.4	5.7	3.2	2.9	2.5

TABLE 2. DIET COMPOSITION

Ingredient	Percent of DM[a]
Corn (IFN 4-02-931)	80.0
Supplement:	
Cottonseed hulls (IFN 1-01-599)	14.05
Molasses (IFN 4-04-696)	1.39
Limestone (IFN 6-02-632)	1.23
Potassium chloride	1.08
Urea	.90
Sodium sulfate	.53
Dicalcium phosphate (IFN 6-01-080)	.35
Salt, trace mineralized[b]	.27
Chromic oxide[c]	.18
Vitamin A[d]	.01

[a] Dry matter basis.
[b] Morton Salt Co., Chicago, IL. 60606.
[c] Added as an indigestible marker.
[d] Contained 30,000 IU/g to provide 3,000 IU/kg feed.

TABLE 3. DRY MATTER PASSAGE AND DIGESTIBILITY

Nutrient	Water Percentage					SE
	15	20	25	30	35	
DM intake, g/day	9229	9981	9297	9151	8792	936
Duodenal passage, g/day	3614^{bc}	4366^{ab}	4530^{a}	4073^{abc}	3557^{c}	534
Ileal passage, g/day	2492	2672	2499	2630	2152	402
Fecal output, g/day	2006^{ab}	2225^{a}	2020^{ab}	2235^{a}	1565^{b}	337
Digestibility, % of input						
Rumen	60.3^{a}	56.6^{ab}	50.9^{c}	55.4^{b}	59.7^{ab}	3.0
Small intestine	31.7	37.3	45.7	35.2	37.7	13.2
Large intestine	19.0	17.8	17.8	16.1	26.8	9.8
Total tract	78.3^{ab}	77.8^{ab}	78.4^{ab}	76.0^{b}	82.1^{a}	3.5

^{a,b,c} Means in a row with different superscripts differ ($P<.05$).

TABLE 4. ORGANIC MATTER PASSAGE AND DIGESTIBILITY

Nutrient	Water Percentage					SE	OC[a]
	15	20	25	30	35		
OM intake, g/day	8812	9458	8847	8743	8374	887	
Duodenal passage, g/day							
Total	3001	3579	3721	3375	2822	434	2
Microbial	1059	1146	1400	1261	1279	164	1
Ileal passage, g/day	2143	2308	2171	2192	1813	347	
Fecal output, g/day	1788	1947	1774	1947	1364	311	2
Digestibility, % of input							
Rumen							
Apparent	65.5	62.6	58.0	61.3	66.5	2.7	2
Adjusted[b]	77.4	74.7	74.0	75.8	81.9	2.9	2
Small intestine	29.6	33.0	42.5	34.4	33.4	13.2	
Large intestine	15.6	16.9	16.8	12.2	24.2	10.0	
Total tract	79.7	79.5	80.0	78.1	83.6	3.4	

[a] Highest order orthogonal contrast ($P<.05$) with 1 being linear, 2 being quadratic, 3 being cubic and 4 being quartic. Blank being no difference.

[b] Adjusted for amount of microbial OM present in duodenal sample.

TABLE 5. STARCH PASSAGE AND DIGESTIBILITY

Nutrient	Water Percentage					SE	OC[a]
	15	20	25	30	35		
Starch intake, g/day	5037	5393	5834	5662	5284	540	2
Duodenal passage, g/day	658	681	637	376	227	278	1
Ileal passage, g/day	253	234	193	96	26	125	1
Fecal output, g/day	116	119	81	23	16	54	1
Amount disappearing, g/day							
Rumen	4771	5186	4824	4983	4915	238	
Small intestine	405	447	444	284	201	96	
Large intestine	137	115	112	68	10	43	
Total tract	5312	5748	5380	5335	5126	251	
Digestibility, % of input							
Rumen	86.7	87.7	89.1	93.0	95.7	5.3	1
Small intestine	65.5	58.0	71.7	68.5	87.8	18.7	
Large intestine	47.2	46.8	44.9	72.4	53.4	33.7	
Total tract	97.7	97.8	98.7	99.6	99.7	1.1	1

[a] Highest order orthogonal contrast ($P<.05$) with 1 being linear, 2 being quadratic, 3 being cubic and 4 being quartic. Blank being no difference.

TABLE 6. NITROGEN PASSAGE AND DIGESTIBILITY

Nutrient	Water Percentage					SE	OC[a]
	15	20	25	30	35		
Ruminal NH_3-N, mg/dl	21.3	19.6	12.8	17.5	18.8	5.5	
N intake, g/day	172	192	169	163	164	17.4	
Duodenal N passage, g/day							
Total	143	179	181	165	156	23.6	2
Microbial	76.3	82.6	100.9	90.4	92.2	11.8	1
Ammonia	7.3	8.1	8.1	8.9	8.5	.8	
Feed	59.1	88.5	72.3	65.6	55.7	5.7	2
Ileal passage, g/day	62	66	60	65	51	12.5	
Fecal output, g/day	57	65	57	59	43	11.0	2
Digestibility, % of input							
Rumen	16.6	6.9	-9.7	-1.2	4.6	11.2	2
Small intestine	55.6	62.3	66.8	59.8	66.5	10.2	
Total tract	67.4	66.4	66.0	64.1	73.4	6.2	
Ruminal bypass, % of corn N	48.4	63.7	64.9	58.5	48.8	5.1	
Microbial efficiency[b]	11.0	11.8	15.5	13.7	13.5	1.0	4
Ruminal dilution rate							
% per hour[c]	7.0	8.8	9.0	8.9	8.1	.9	
% per hour[d]	2.9	3.4	5.0	3.8	4.1	.7	

[a] Highest order orthogonal contrast ($P<.05$) with 1 being linear, 2 being quadratic, 3 being cubic and 4 being quartic. Blank being no difference.

[b] Grams of bacterial N per kg of OM truly fermented in the rumen.

[c] Calculated from fluid flow to the duodenum assuming a 50 liter ruminal volume and equal absorption and secretion of fluid from the rumen to the duodenum.

[d] Calculated from ammonia flow to the duodenum and ruminal ammonia concentrations based on equal absorption and secretion of ammonia from the rumen to the duodenum.

TABLE 7. ACID DETERGENT FIBER PASSAGE AND DIGESTIBILITY

Nutrient	Water Percentage					SE	OC[a]
	15	20	25	30	35		
ADF intake, g/day	1390	1446	1163	1135	1069	130	1
Duodenal passage, g/day	559	690	771	720	482	57	2
Ileal ADF passage, g/day	751	758	745	884	729	134	
Fecal ADF output, g/day	710	749	716	867	613	136	
Amount disappearing, g/day							
Rumen	662	633	463	606	700	89	
Small intestine	-192	-68	26	-163	-246	119	
Large intestine	42	9	29	16	116	43	
Total tract	511	574	519	359	570	55	3
Digestibility, % of input							
Rumen	59.1	52.8	34.3	37.5	55.3	14.5	2
Small intestine	-37.6	-24.1	.5	-33.3	-68.6	53.0	
Large intestine	2.9	2.4	2.1	.0	15.4	12.6	
Total tract	49.0	48.2	38.2	24.7	42.6	9.6	3

[a] Highest order orthogonal contrast ($P<.05$) with 1 being linear, 2 being quadratic, 3 being cubic and 4 being quartic. Blank being no difference.

TABLE 8. ASH PASSAGE AND DIGESTIBILITY

Nutrient	Water Percentage					SE	OC[a]
	15	20	25	30	35		
Ash intake, g/day	462	430	465	429	421	46	1
Duodenal passage, g/day	613	788	809	697	736	174	
Ileal ash passage, g/day	349	364	327	438	339	66.5	4
Fecal ash output, g/day	219	278	246	289	201	35.5	4
Digestibility, % of input							
Rumen	-35.6	-49.7	-83.6	-63.2	-75.4	32.4	
Small intestine	39.4	51.4	56.6	36.7	53.0	19.0	
Large intestine	37.5	26.6	24.3	34.5	39.8	13.2	2
Total tract	52.5	47.5	46.9	33.4	51.8	8.2	3

[a] Highest order orthogonal contrast ($P<.05$) with 1 being linear, 2 being quadratic, 3 being cubic and 4 being quartic. Blank being no difference.

TABLE 9. DIGESTIVE TRACT pH

Site	Moisture Content, %					SE	OC[a]
	15	20	25	30	35		
Rumen	6.08	6.20	5.88	5.97	5.56	.23	4
Proximal duodenum	2.67	3.06	3.02	2.98	3.01	.14	3
Distal ileum	6.23	6.78	7.57	7.74	8.09	.32	
Rectum	5.85	5.96	6.20	6.41	7.05	.35	

[a] Highest order orthogonal contrast ($P<.05$) with 1 being linear, 2 being quadratic, 3 being cubic and 4 being quartic. Blank being no difference.

CHAPTER VI

SITE OF DIGESTION OF WHOLE SHELLED, ROLLED AND STEAM FLAKED CORN IN HEIFERS

Summary

Whole shelled corn (WS), rolled (RC) and steam flaked corn (SF) were fed to three heifers (203 kg) equipped with ruminal, duodenal and ileal cannulas in a latin square experiment and site of digestion was measured. Total tract digestibilities of dry matter (DM), organic matter (OM), and starch were highest with steam flaked corn. OM digestibility in the rumen, adjusted for microbial OM, did not differ markedly among treatments (65, 69 and 70 percent for WS, RC and SF, respectively). Disappearance of starch in the rumen, small intestine and large intestine, expressed as a percentage of starch entering each segment, all increased with processing of grain. Starch disappearance in the small intestine, expressed as percent of dietary starch or grams per day, was similar for the three processing methods. Efficiency of microbial protein synthesis was highest for WS. Results support the concept that factors such as particle size or surface exposure which limit ruminal starch digestion also limit small intestinal digestion of starch.

Introduction

The principal purpose for processing grain is to improve feed

efficiency. Consequently, processing often increases digestibility of grain often through increasing the surface area or reducing particle size of grains. Processing also may depress digestibility of roughages and increase the incidence of acidosis. Particle exposure is one factor which may limit the extent of starch digestion by ruminant animals (Galyean et al., 1977). Processing and particle size changes also may alter site of digestion by ruminant animals. One common processing method, steam flaking, which disrupts starch granules of grains, may not be economical in the future if the price of energy relative to the price of grain continues to increase. A fuller understanding of grain processing on site of digestion is needed to explain efficiency advantages for certain processing methods (Hale, 1980) and to modify processing so as to maximize profit. The objective of this study was to determine the effect of processing method on site of nutrient digestion of corn grain by feedlot cattle.

Materials and Methods

One batch of dent yellow corn obtained from a commercial feedlot in Arkansas City, OK. was fed without processing or processed by steam flaking at the feedyard or by rolling immediately prior to feeding. All SF was stored frozen prior to feeding. Chemical composition and for the three types of corn are presented in table 1. Diet DM consisted of 90% corn and 10% supplement (table 2) formulated to meet the nutrient requirements for growing heifers (NRC, 1976). Chromic oxide was included as an indigestible marker.

To determine site and extent of digestion of DM, OM, starch, protein and fiber digestion, three heifers (203 kg) were fed the three corn types in a latin square experiment. Heifers were equipped with ruminal, duodenal and ileal cannulas. Heifers were fed twice daily (0800 and 2000 h) with dry matter intake restricted to 1.8 percent of of body weight to avoid digestive upsets and feed refusals.

Each 12 day period consisted of 9 days for adaptation to the new diet and three days for collection of digesta samples. Ruminal, duodenal, ileal and fecal samples were collected in the morning and afternoon of each sampling day and composited within animal and period for analysis.

Chemical analysis of the samples and statistical analysis of the data followed the procedures described previously (Aguirre, E. 1984. Op.Cit. Chapter V).

Results and Discussion

Digestibility of DM and OM in the total digestive tract (tables 3 and 4; Appendix tables 30 and 31) tended to be higher for SF than WS ($P<.09$; $P<.07$). Grinding will fracture the kernel and increase the surface area for digestion by microbes and digestive enzymes. In addition, flaking will rupture some of the starch granules and increase rate of digestion. Digestibility in the rumen, small and large intestine all tended to increase with processing. This contrasts with the common belief that digestion in the small intestine will increase to compensate for a reduction in digestion in the rumen. Certainly, intestinal compensation is possible when ruminal digestion is depressed by a high level of feed intake, but compensation for

incomplete processing in this trial was not apparent. Instead, results indicate that a common factor, such as particle size, may limit digestion both in the rumen and in the small intestine. This is not surprising, since whole grain which escapes ruminal digestion usually passes trough the entire intestinal tract of either ruminants and swine unscathed (Rust, 1983).

Starch digestibility (table 5; Appendix table 32) also tended to be greater ($P<.09$) for SF than WS. This suggests that physical alteration of corn grain beyond mastication is needed maximize starch digestibility. Ruminal starch digestibility and ruminal pH were negatively related (tables 5 and 9). Similar effects of processing on total tract starch digestion of starch were reported by Gill et al. (1980).

Protein passage and digestibilities were not affected ($P>.05$) by grain processing in this experiment (table 6). However, duodenal passage of microbial N (Appendix table 33) tended to be greater for WS than for processed corn types. This may reflect a faster fluid passage rate with this diet due either to the high density of WS which may simplify flow of liquid from the rumen (Hale, 1980) or to increased mastication and rumination which would increase salivary input and increase liquid dilution rate. Bypass of dietary protein tended to be higher reported previously (57 and 73%) for corn grain (Zinn and Owens, 1983). Reasons for the difference are not apparent though feed intake were higher and ruminal pH may have been lower in this trial than in other reports. Lower pH may enhance ruminal bypass (Weakley, 1983). Hinman and Johnson (1974) reported that steam flaking of milo grain increased passage of milo protein to the small

intestine. Protein bypass tended to be greater for SF than WS or RC in this experiment and for all three than high moisture corn in a previous trial (Aguirre, Op Cite, Chapter V), but differences were small.

The ADF content of grain appeared to decline with processing method (table 7). As discussed previously (Aguirre, E. 1984. Op.Cit. Chapter V). this may be an analytical artifact. Digestibility of ADF in the rumen tended to decline ($P>.05$) as the extent of processing increased, but digestion in the large intestine compensated for the reduced digestion in the rumen. Similar to effects in the rumen, a low pH in the large intestine may inhibit fermentation of ADF.

Ash digestibilities in the rumen were negative and may reflect salivary input (table 8; Appendix table 34). Flow of ash to the duodenum paralleled microbial efficiency and may reflect ruminal liquid dilution rate.

In addition to cost and effectiveness of grain processing, factors which must be considered when comparing methods include roughage availability, animal health and management, bunk life of diet and diet handling and mixing capabilities (Gill et al., 1978).

TABLE 1. CHEMICAL COMPOSITION OF THREE TYPES OF CORN

Item	Processing Method		
	Whole	Rolled	Steam Flaked
Dry matter, %	87.7	87.7	82.4
Protein			
Total, % of DM	10.6	10.8	10.6
Soluble, % of total	17.3	18.3	12.8
Starch, % of DM	75.9	76.1	74.7
Ash, % of DM	1.6	1.4	1.3
Acid detergent fiber, % of DM	5.0	4.3	3.6

TABLE 2. DIET COMPOSITION

Ingredient	Percent of DM[a]
Corn (IFN 4-02-931)	90.0
Supplement:	
Cottonseed hulls (IFN 1-01-599)	4.91
Potassium chloride	1.38
Urea	1.26
Limestone (IFN 6-02-632)	.90
Sodium sulfate	.69
Molasses (IFN 4-04-696)	.50
Dicalcium phosphate (IFN 6-01-080)	.11
Chromic oxide[b]	.20
Salt, trace mineralized[c]	.04
Vitamin A[d]	.01

[a] Dry matter basis.
[b] Added as an indigestible marker.
[c] Morton Salt Co., Chicago, IL. 60606.
[d] Contained 30,000 IU/g to provide 3,000 IU/kg feed.

TABLE 3. DRY MATTER PASSAGE AND DIGESTIBILITY

Item	Processing Method			SE
	Whole	Rolled	Steam Flaked	
DM intake, g/day	3212	3218	3025	75.7
Duodenal DM, g/day	1822	1580	1490	83.0
Ileal DM, g/day	763[a]	696[ab]	600[b]	143.5
Fecal DM, g/day	668[a]	480[ab]	397[b]	43.5
Digestibility, % of input				
Rumen	43.3	50.8	50.4	2.7
Small intestine	58.3	57.4	59.6	6.5
Large intestine	11.8[b]	25.1[ab]	33.3[a]	11.1
Total tract	79.2[b]	85.1[ab]	86.8[a]	1.1

[a,b] Means in a row with different superscripts differ ($P<.05$).

TABLE 4. ORGANIC MATTER PASSAGE AND DIGESTIBILITY

Item	Processing Method			
	Whole	Rolled	Steam Flaked	SE
OM intake, g/day	3069	3081	2903	71.2
Duodenal OM, g/day	1551	1354	1261	76.6
Duodenal microbial OM g/day	478	398	390	33.0
Ileal OM, g/day	653	635	530	135.9
Fecal OM, g/day	629	444	364	43.9
Digestibility, % of input				
Rumen	49.4	56.0	65.0	2.4
Rumen, adjusted	64.9	69.1	69.8	2.8
Small intestine	58.0	55.2	58.1	7.5
Large intestine	3.3^{b}	22.8^{ab}	30.8^{a}	11.7
Total tract	79.5^{b}	85.6^{ab}	87.4^{a}	1.2

^{a,b} Means in a row with different superscripts differ ($P<.05$).

TABLE 5. STARCH PASSAGE AND DIGESTIBILITY

Item	Processing Method			
	Whole	Rolled	Steam Flaked	SE
Starch intake, g/day	2216	2226	2048	51.8
Duodenal starch, g/day	564	498	349	59.1
Ileal starch, g/day	192	161	45	62.2
Fecal starch, g/day	124	79	15	20.2
Amount digested, g/day				
Rumen	1652	1728	1699	73.0
Small intestine	372	338	305	16.4
Large intestine	68	81	30	43.0
Total tract	2093	2147	2033	57.2
Digestibility, % of input				
Rumen	74.6	77.6	82.7	2.5
Small intestine	66.8	70.7	88.0	8.8
Large intestine	32.6_{b}	39.2_{ab}	61.2_{a}	17.3
Total tract	94.5^{b}	96.4^{ab}	99.3^{a}	.8

^{a,b} Means in a row with different superscripts differ ($P<.05$).

TABLE 6. NITROGEN PASSAGE AND DIGESTIBILITY

Item	Processing Method			SE
	Whole	Rolled	Steam Flaked	
N intake, g/day	72.0	73.3	68.3	1.7
Ruminal NH_3-N, mg/dl	4.7	7.0	7.0	.3
Duodenal N, g/day				
Total	80.6	73.5	74.6	2.0
Microbial	34.4	28.7	28.1	2.4
Ammonia-N	3.5	4.0	3.5	.13
Dietary	42.6	40.8	42.9	4.1
Ileal N, g/day	21.0	18.2	19.6	2.9
Fecal N, g/day	22.1	21.2	16.9	3.2
Protein bypass				
% of corn protein	85.4	79.2	87.9	7.8
Digestibility, % of input				
Rumen	-11.9	-0.7	-9.7	5.1
Small intestine	74.3[b]	75.2[a]	73.6[a]	4.1
Large intestine	-8.3[b]	14.2[a]	14.3[a]	3.1
Total tract	69.4[a]	70.9[b]	75.2[ab]	4.4
Microbial efficiency[c]	17.1[a]	13.4[b]	14.2[ab]	.5
Ruminal liquid dilution				
rate, % per hour[d]	6.4	4.9	4.6	.65
rate, % per hour[e]	3.5	2.9	2.7	.68

[a,b] Means in a row with different superscripts differ ($P<.05$).

[c] Expressed as grams of microbial N per kg of OM truly fermented in the rumen.

[d] Calculated from duodenal liquid flow assuming a ruminal volume of 50 liters and equal absorption and excretion between the rumen and the duodenum.

[e] Calculated from ammonia flow to the duodenum and ruminal ammonia concentrations based on equal absorption and secretion of ammonia from the rumen to the duodenum.

TABLE 7. ACID DETERGENT FIBER PASSAGE AND DIGESTIBILITY

Item	Processing Method			
	Whole	Rolled	Steam Flaked	SE
ADF intake, g/day	259[a]	240[ab]	210[b]	5.4
Duodenal ADF, g/day	126	128	143	9.7
Ileal ADF, g/day	107	110	124	18.2
Fecal ADF, g/day	106	99	97	14.0
Amount digested, g/day				
Rumen	133	112	68	14.9
Small intestine	19.2	17.6	18.7	12.2
Large intestine	.3	12.0	26.4	19.5
Total tract	152	142	112	14.3
Digestibility, % of input				
Rumen	50.4	46.5	31.1	5.7
Small intestine	10.2	11.6	10.7	8.9
Large intestine	1.0	7.7	19.0	14.9
Total tract	58.0	58.9	53.4	5.3

[a,b] Means in a row with different superscripts differ ($P<.05$).

TABLE 8. ASH PASSAGE AND DIGESTIBILITY

Item	Processing Method			SE
	Whole	Rolled	Steam Flaked	
Ash intake, g/day	142	136	126	3.4
Duodenal Ash, g/day	272	226	220	17.4
Ileal Ash, g/day	110[a]	61[b]	70[ab]	7.9
Fecal Ash, g/day	39	36	34	1.4
Digestibility, % of input				
Rumen	-88.7[a]	-65.9[b]	-75.9[ab]	17.1
Small intestine	58.7	72.7	68.2	1.7
Large intestine	62.7	41.2	50.2	5.6
Total tract	72.3	73.7	73.2	.5

[a,b] Means in a row with different superscripts differ ($P<.05$).

TABLE 9. DIGESTIVE TRACT pH

Site	Processing Method			SE
	Whole	Rolled	Steam Flaked	
Rumen	5.93	6.18	5.84	.13
Proximal duodenum	2.45	2.19	2.61	.12
Terminal ileum	7.36	6.01	7.15	.38
Rectum	5.80	5.75	6.32	.15

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

The experiments outlined in this thesis will be summarized and compared with literature findings in the following discussion. Results from the experiment with addition of moisture to high moisture corn (HMC) at ensiling time indicate that the extent of fermentation appears to be directly related to the amount of water present in the corn grain. Addition of water resulted in an increase in starch and the solubility of protein in a saline solution. With fermentation, DM, OM and pH decreased while solubility of protein and availability of starch increased.

Compared with wetting the grain at feeding time, allowing the corn to ferment increased feed intake, gains and efficiencies of lambs. Moisture content of grain did not affect dry matter intake by lambs, but gains and efficiencies decreased as corn moisture content increased. In contrast with these results, most literature reports indicate that feed intake is reduced when ensiled high moisture corn and milo grains contain higher amounts of moisture. This depression in feed intake has been attributed to an increase in nitrogen solubility or in acid load of the animals. In this trial, urea was used as the sole source of supplemental nitrogen. Since urea is completely soluble and feed intake was not reduced as solubility of

nitrogen increased with moisture added to the HMC, protein solubility may not be responsible for reduced feed intake of wetter HMC. However, in this study corn was reconstituted rather than harvested at a high moisture content. This may have altered levels of certain chemical components, such as amines and ethanol, though final moisture had more impact than initial moisture content on chemical components of HMC formed during fermentation in trial 1. Also, diets were fed to lambs in this trial compared with steers in most trials reported in the literature, and animal factors, such as the potential for subclinical acidosis, may differ with animal species.

In the lamb study, digestibility of starch as well as starch content increased linearly as water was added while ADF content and ADF digestibility declined. Since starch and ADF digestibilities were similar for wetted grain and fermented grain, these effects appear not to be related to fermentation but instead to moisture content. This conflicts with the concept that fermentation periods lasting several weeks are needed to maximize starch digestibility of milo grain. Because starch composed a larger fraction of the DM and OM of the diet than ADF, the changes in digestibility of starch and ADF caused digestibility of DM and OM to increase with moisture content of the grain. Possibly, added moisture decreased influx of saliva. Reduced input of saliva would reduce ruminal pH which in turn depresses rate of fiber digestibility and may increase rate of starch digestion. To check this theory, further study of the influence of fermentation of grain on ruminal buffering and fiber and starch digestion in the rumen is needed.

In the steer trial, extent of digestion of corn protein in the rumen did not increase as moisture content of HMC was increased despite greater solubility of N in wetter grain. This conflicts with the general premise of the literature that the greater the solubility, the greater the extent of destruction of protein in the rumen. This premise originated from the observation that many soluble proteins, such as casein, are completely digested in the rumen while certain insoluble proteins, such as zein, survive ruminal digestion. Several explanations for the high ruminal escape despite the higher solubility may be offered. First, with added moisture, ruminal pH was lower. Microbial proteolysis in the rumen decreases as pH decreases. Secondly, the protein solubilized during fermentation may be the same protein which would otherwise be digested during passage through the rumen, so that rate but not extent of ruminal protein digestion is changed by pre-fermenting corn grain.

As moisture content of HMC was increased, the extent of ruminal starch digestion increased paralleling the increase in availability of the starch noted in the first trial with added moisture. In addition, ruminal dilution rate and efficiency of microbial growth both were lowest with dry corn and appeared to increase with moisture level up to 25%. As starch digestion in the rumen is increased with added moisture, more non-protein nitrogen (NPN) can be used by bacteria and should be supplied. As moisture level increased, availability of energy increased more than availability of nitrogen digestion in the rumen. Hence, more of the nitrogen recycled to the rumen was used by ruminal bacteria. These results suggest that higher levels of NPN could be used with fermented than with dry grain since ruminal

nitrogen need is increased more than nitrogen supply by fermentation. In addition, the amount of protein passing to the duodenum and digested from the small intestine peaked at about 25% moisture due to increases in the flow of microbial protein.

In the site of digestion trial with heifers, digestibility of DM, OM and starch in the rumen, small and large intestine all tended to increase with more extensive grain processing. As processing reduced particle size, this supports the concept that particle size may limit digestion at all sites. No increase in digestibility of starch in the intestines to compensate for reduced digestion in the rumen was noted. This matches the particle size theory, also, since starch escaping digestion in the rumen which has a large particle size, as with whole shelled corn, will pass through the intestines largely unchanged, while starch escaping ruminal digestion from ground or flaked grain can be digested by intestinal enzymes or bacteria more readily.

Finally, results of this thesis revealed unexpected changes in chemically determined starch and acid detergent fiber contents of feeds. Previously, these analytical procedures have not been questioned though they have not been specifically tested with corn processing methods as in this series of experiments. Values differed considerably with fermentation, moisture level and processing of corn grain. Tests of the validity of these analytical procedures with processed feedstuffs are needed.

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APPENDIX

ANALYSIS OF VARIANCE TABLES

TABLE 1. ANALYSIS OF VARIANCE FOR DRY MATTER

Source	DF	SS	F	P<
Treatments	1	3.82	10.95	.01
Initial water (blocks)	7	74.92	30.73	.01
Initial water * Trt.	7	2.44	1.15	.38
Sampling error	16	4.85		
Corrected total	31	86.02		

TABLE 2. ANALYSIS OF VARIANCE FOR ORGANIC MATTER

Source	DF	SS	F	P<
Treatments	1	3.27	85.52	.02
Initial water (blocks)	7	71.64	26.61	.01
Initial water * Trt.	7	2.69	.96	.49
Sampling error	16	6.43		
Corrected total	31	84.04		

TABLE 3. ANALYSIS OF VARIANCE FOR pH

Source	DF	SS	F	P<
Treatments	1	12.01	70.32	.01
Initial water (blocks)	7	.54	.45	.84
Initial water * Trt.	7	1.20	12.42	.01
Sampling error	16	.22		
Corrected total	31	13.96		

TABLE 4. ANALYSIS OF VARIANCE FOR SOLUBLE PROTEIN

Source	DF	SS	F	P<
Treatments	1	828.39	15.94	.01
Initial water (blocks)	7	906.33	2.49	.13
Initial water * Trt.	7	363.81	1.52	.23
Sampling error	16	548.26		
Corrected total	31	2646.79		

TABLE 5. ANALYSIS OF VARIANCE FOR AVAILABLE STARCH

Source	DF	SS	F	P<
Treatments	1	204.18	3.83	.09
Initial water (blocks)	7	89.65	.24	.96
Initial water * Trt.	7	372.82	4.59	.01
Sampling error	16	185.77		
Corrected total	31	852.42		

TABLE 6. ANALYSIS OF VARIANCE FOR DRY MATTER INTAKE

Source	DF	SS	F	P<
Fermentation (F)	1	.155	8.93	.01
Moisture level (M)	1	.004	.22	.64
M * M	1	.030	1.71	.20
M * M * M	1	.004	.22	.64
M * M * M * M	1	.045	2.60	.11
M * F	1	.042	2.39	.13
M * M * F	1	.032	1.85	.18
M * M * M * F	1	.003	.18	.67
M * M * M * M * F	1	.00012	.01	.93
Error	49	.85		
Corrected total	58	1.17		

TABLE 7. ANALYSIS OF VARIANCE FOR AVERAGE DAILY GAIN

Source	DF	SS	F	P<
Fermentation (F)	1	.0161	7.71	.01
Moisture level (M)	1	.0183	8.75	.01
M * M	1	.0018	.87	.35
M * M * M	1	.0009	.42	.52
M * M * M * M	1	.0025	1.21	.28
M * F	1	.0152	7.28	.01
M * M * F	1	.0005	.24	.63
M * M * M * F	1	.0005	.24	.63
M * M * M * M * F	1	.0005	.23	.63
Error	49	.1024		
Corrected total	58	.1588		

TABLE 8. ANALYSIS OF VARIANCE FOR FEED EFFICIENCY

Source	DF	SS	F	P<
Fermentation (F)	1	11.96	4.23	.05
Moisture level (M)	1	29.04	10.26	.01
M * M	1	1.35	.48	.49
M * M * M	1	2.26	.80	.38
M * M * M * M	1	.50	.18	.68
M * F	1	14.21	5.02	.03
M * M * F	1	3.7201	1.32	.26
M * M * M * F	1	.09	.03	.86
M * M * M * M * F	1	1.67	.59	.45
Error	49	138.68		
Corrected total	58	203.50		

TABLE 9. ANALYSIS OF VARIANCE FOR DRY MATTER DIGESTIBILITY

Source	DF	SS	F	P<
Fermentation (F)	1	.0062	8.09	.01
Moisture level (M)	1	.0007	.85	.37
M * M	1	.0005	.66	.43
M * M * M	1	.0006	.82	.38
M * M * M * M	1	.0000	.00	.96
M * F	1	.0015	1.92	.18
M * M * F	1	.0001	.13	.72
M * M * M * F	1	.0003	.46	.51
M * M * M * M * F	1	.0004	.52	.48
Error	49	.0152		
Corrected total	58	.0255		

TABLE 10. ANALYSIS OF VARIANCE FOR OM DIGESTIBILITY

Source	DF	SS	F	P<
Fermentation (F)	1	.0073	9.59	.01
Moisture level (M)	1	.0008	.99	.33
M * M	1	.0006	.78	.39
M * M * M	1	.0005	.66	.43
M * M * M * M	1	.0000	.00	.94
M * F	1	.0017	2.23	.15
M * M * F	1	.0001	.15	.70
M * M * M * F	1	.0003	.37	.55
M * M * M * M * F	1	.0004	.67	.46
Error	49	.0153		
Corrected total	58	.0270		

TABLE 11. ANALYSIS OF VARIANCE FOR STARCH DIGESTIBILITY

Source	DF	SS	F	P<
Fermentation (F)	1	.0000	.12	.74
Moisture level (M)	1	.0014	27.77	.01
M * M	1	.0000	.05	.83
M * M * M	1	.0001	1.28	.27
M * M * M * M	1	.0000	.14	.71
M * F	1	.0001	1.40	.25
M * M * F	1	.0002	3.07	.10
M * M * M * F	1	.0001	2.65	.12
M * M * M * M * F	1	.0000	.83	.37
Error	49	.0010		
Corrected total	58	.0029		

TABLE 12. ANALYSIS OF VARIANCE FOR ADF DIGESTIBILITY

Source	DF	SS	F	P<
Fermentation (F)	1	.0229	13.10	.01
Moisture level (M)	1	.0152	8.69	.01
M * M	1	.0033	1.87	.17
M * M * M	1	.0044	2.54	.13
M * M * M * M	1	.0028	1.63	.22
M * F	1	.0022	1.24	.28
M * M * F	1	.0001	.06	.80
M * M * M * F	1	.0016	.93	.35
M * M * M * M * F	1	.0006	.33	.57
Error	49	.0349		
Corrected total	58	.0880		

TABLE 13. ANALYSIS OF VARIANCE FOR RUMEN DM DIGESTIBILITY

Source	DF	SS	F	P<
Treatment	4	.0286	8.34	.01
Linear	1	.0002	.24	.64
Quadratic	1	.0255	29.77	.01
Cubic	1	.0000	0.0	.99
Quartic	1	.0029	3.42	.09
Error	11	.0094		
Corrected total	23	.0742		

TABLE 14. ANALYSIS OF VARIANCE FOR TOTAL TRACT DRY MATTER DIGESTIBILITY

Source	DF	SS	F	P<
Treatment	4	.01	2.13	.15
Linear	1	.002	1.41	.26
Quadratic	1	.004	3.27	.10
Cubic	1	.003	2.48	.14
Quartic	1	.002	1.35	.27
Error	11	.0129		
Corrected total	23	.0471		

TABLE 15. ANALYSIS OF VARIANCE FOR RUMEN ADJUSTED ORGANIC MATTER DIGESTBILITY

Source	DF	SS	F	P<
Treatment	4	.0194	6.08	.01
Linear	1	.0058	7.26	.02
Quadratic	1	.0160	19.99	.01
Cubic	1	.0000	0.0	.95
Quartic	1	.0003	.42	.53
Error	11	.0088		
Corrected total	23	.0876		

TABLE 16. ANALYSIS OF VARIANCE FOR TOTAL TRACT OM DIGESTIBILITY

Source	DF	SS	F	P<
Treatment	4	.0085	1.97	.17
Linear	1	.0020	1.85	.20
Quadratic	1	.0030	2.76	.12
Cubic	1	.0024	2.19	.17
Quartic	1	.0011	1.05	.33
Error	11	.0118		
Corrected total	23	.0428		

TABLE 17. ANALYSIS OF VARIANCE FOR RUMEN STARCH DIGESTIBILITY

Source	DF	SS	F	P<
Treatment	4	.0300	2.61	.09
Linear	1	.0278	10.39	.01
Quadratic	1	.0016	.61	.45
Cubic	1	.0006	.22	.65
Quartic	1	.0000	.0	.94
Error	11	.0294		
Corrected total	23	.0759		

TABLE 18. ANALYSIS OF VARIANCE FOR SMALL INTESTINAL STARCH DIGESTIBILITY

Source	DF	SS	F	P<
Treatment	4	.2269	1.70	.22
Linear	1	.1144	3.42	.09
Quadratic	1	.0330	.98	.34
Cubic	1	.0096	.29	.60
Quartic	1	.0197	.59	.46
Error	11	.3674		
Corrected total	23	1.1987		

TABLE 19. ANALYSIS OF VARIANCE FOR TOTAL TRACT STARCH DIGESTIBILITY

Source	DF	SS	F	P<
Treatment	4	.0020	3.58	.04
Linear	1	.0018	14.26	.01
Quadratic	1	.0000	.00	.97
Cubic	1	.0002	1.53	.24
Quartic	1	.0000	.05	.83
Error	11	.3674		
Corrected total	23	1.1987		

TABLE 20. ANALYSIS OF VARIANCE FOR RUMEN N DIGESTIBILITY

Source	DF	SS	F	P<
Treatment	4	.1892	3.99	.03
Linear	1	.0576	4.86	.05
Quadratic	1	.1058	8.93	.01
Cubic	1	.0022	.19	.67
Quartic	1	.0337	2.85	.12
Error	11	.1304		
Corrected total	23	.4483		

TABLE 21. ANALYSIS OF VARIANCE FOR MICROBIAL N PASSAGE

Source	DF	SS	F	P<
Treatment	4	1744.49	3.28	.05
Linear	1	810.02	6.10	.03
Quadratic	1	519.29	3.84	.08
Cubic	1	.23	0.0	.97
Quartic	1	502.20	3.78	.08
Error	11	1460.56		
Corrected total	23	7292.36		

TABLE 22. ANALYSIS OF VARIANCE FOR MICROBIAL EFFICIENCY

Source	DF	SS	F	P<
Treatment	4	62.48	14.57	.01
Linear	1	23.25	22.34	.01
Quadratic	1	20.76	19.94	.01
Cubic	1	.45	.44	.52
Quartic	1	18.02	17.31	.01
Error	11	11.45		
Corrected total	23	100.66		

TABLE 23. ANALYSIS OF VARIANCE FOR RUMEN ADF DIGESTIBILITY

Source	DF	SS	F	P<
Treatment	4	.2456	3.08	.06
Linear	1	.0178	.89	.37
Quadratic	1	.1977	9.93	.01
Cubic	1	.0146	.74	.41
Quartic	1	.0045	.23	.64
Error	11	.2190		
Corrected total	23	.7114		

TABLE 24. ANALYSIS OF VARIANCE FOR TOTAL TRACT ADF DIGESTIBILITY

Source	DF	SS	F	P<
Treatment	4	.1890	5.35	.01
Linear	1	.0606	6.80	.02
Quadratic	1	.0442	5.00	.05
Cubic	1	.0802	9.07	.01
Quartic	1	.0047	.53	.48
Error	11	.2190		
Corrected total	23	.7114		

TABLE 25. ANALYSIS OF VARIANCE FOR RUMEN ASH DIGESTIBILITY

Source	DF	SS	F	P<
Treatment	4	.7329	4.58	.19
Linear	1	.4879	4.78	.05
Quadratic	1	.0946	.95	.35
Cubic	1	.0000	0.0	.98
Quartic	1	.2664	2.67	.13
Error	11	1.0977		
Corrected total	23	3.9289		

TABLE 26. ANALYSIS OF VARIANCE FOR RUMEN pH

Source	DF	SS	F	P<
Treatment	4	.8791	4.25	.05
Linear	1	.6014	11.64	.01
Quadratic	1	.1054	2.04	.20
Cubic	1	.0186	.36	.58
Quartic	1	.2881	5.58	.05
Error	7	.3617		
Corrected total	18	1.9007		

TABLE 27. ANALYSIS OF VARIANCE FOR DUODENAL pH

Source	DF	SS	F	P<
Treatment	4	.4973	6.57	.01
Linear	1	.1902	10.33	.01
Quadratic	1	.1738	9.43	.01
Cubic	1	.1216	6.60	.03
Quartic	1	.0117	.63	.44
Error	11	.2026		
Corrected total	23	.8190		

TABLE 28. ANALYSIS OF VARIANCE FOR ILEAL pH

Source	DF	SS	F	P<
Treatment	4	11.2304	29.39	.01
Linear	1	10.3849	108.72	.01
Quadratic	1	.4121	4.31	.06
Cubic	1	.0036	.04	.85
Quartic	1	.1378	1.44	.26
Error	11	1.0508		
Corrected total	23	13.7880		

TABLE 29. ANALYSIS OF VARIANCE FOR FECAL pH

Source	DF	SS	F	P<
Treatment	4	4.3627	9.18	.01
Linear	1	3.7323	31.42	.01
Quadratic	1	.3481	2.93	.11
Cubic	1	.0798	.67	.43
Quartic	1	.0106	.09	.77
Error	11	1.3067		
Corrected total	23	7.2416		

TABLE 30. ANALYSIS OF VARIANCE FOR TOTAL TRACT DRY MATTER DIGESTIBILITY

Source	DF	SS	F	P<
Treatment	2	.0095	13.09	.07
Error	2	.0007		
Corrected total	8	.0157		

TABLE 31. ANALYSIS OF VARIANCE FO TOTAL TRACT ORGANIC MATTER DIGESTIBILITY

Source	DF	SS	F	P<
Treatment	2	.0102	12.39	.07
Error	2	.0008		
Corrected total	8	.0167		

TABLE 32. ANALYSIS OF VARIANCE FOR TOTAL TRACT STARCH DIGESTIBILITY

Source	DF	SS	F	P<
Treatment	2	.0035	9.60	.09
Error	2	.0004		
Corrected total	8	.0050		

TABLE 33. ANALYSIS OF VARIANCE FOR MICROBIAL EFFICIENCY

Source	DF	SS	F	P<
Treatment	2	23.1395	9.60	.07
Error	2	1.7434		
Corrected total	8	109.5517		

TABLE 34. ANALYSIS OF VARIANCE FOR SMALL INTESTINAL ASH DIGESTIBILITY

Source	DF	SS	F	P<
Treatment	2	.0309	18.17	.05
Error	2	.0017		
Corrected total	8	.0515		

VITA

ERNESTO AGUIRRE OLIVAS

Candidate for the Degree of

Doctor of Philosophy

Thesis: EFFECT OF FERMENTATION OF CORN GRAIN ON DIGESTION BY RUMINANTS FULL FED HIGH CONCENTRATE DIETS

Major Field: Animal Nutrition

Biographical:

Personal Data: Born in Chihuahua, Chih. Mex., June 5, 1949, the son of Gilberto and Maria Aguirre.

Education: Graduated from Instituto Regional High School, Chihuahua, Chih., Mex., in June, 1968; received of Ingeniero Zootecnista in April, 1974; received Master of Science degree from New Mexico State University in July, 1979; completed requirements for the Doctor of Philosophy degree in Animal Nutrition at Oklahoma State University in July, 1984.

Professional Experience: Soil Laboratory Technician in Secretaria de Recursos Hidraulicos, 1969 to 1972; Appraiser in Departamento de Cooperacion Tecnica, Banco Agropecuario del Norte, S. A., Chihuahua, Chih., Mexico; Teacher in Escuela Superior de Zootecnia, Universidad Autonoma de Chihuahua, 1973 to 1975; Graduate Student at New Mexico State University, 1975 to 1977; Associate Professor in Facultad de Zootecnia, Universidad Autonama de Chihuahua, 1977 to 1981; Graduate Student at Oklahoma State University, 1981 to 1984.

Professional Organizations: Asociacion Mexicana de Ingenieros Zootecnistas, Asociacion Mexicana de Produccion Animal, Asociacion Latinoamericana de Produccion Animal, American Society of Animal Science, Confederacion Nacional de Tiro, American Rifle Association.