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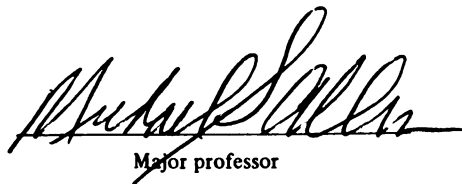
EFFECTS OF FINENESS OF GRINDING AND CONSERVATION
METHOD OF CORN GRAIN ON RUMINAL AND WHOLE TRACT
DIGESTIBILITY, RUMINAL MICROBIAL PROTEIN PRODUCTION,
AND FEEDING BEHAVIOR OF HOLSTEIN HEIFERS BEFORE AND
AFTER CALVING

presented by

YUN YING

has been accepted towards fulfillment
of the requirements for

M. S. degree in ANIMAL SCIENCE



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**EFFECTS OF FINENESS OF GRINDING AND CONSERVATION METHOD OF
CORN GRAIN ON RUMINAL AND WHOLE TRACT DIGESTIBILITY,
RUMINAL MICROBIAL PROTEIN PRODUCTION, AND FEEDING
BEHAVIOR OF HOLSTEIN HEIFERS BEFORE AND AFTER CALVING**

By

Yun Ying

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ABSTRACT

EFFECTS OF FINENESS OF GRINDING AND CONSERVATION METHOD OF CORN GRAIN ON RUMINAL AND WHOLE TRACT DIGESTIBILITY, RUMINAL MICROBIAL PROTEIN PRODUCTION, AND FEEDING BEHAVIOR OF HOLSTEIN HEIFERS BEFORE AND AFTER CALVING

By

Yun Ying

Eight ruminally and duodenally cannulated Holstein heifers were used in a duplicated 4×4 Latin-square design with 21-d periods. Treatments were dry and high moisture corn, ground finely or coarsely. Two experiments were conducted using the same animals before and after calving. High moisture conservation and fine grinding increased rate of starch digestion resulting in increased ruminal starch and OM digestibility for both experiments. High moisture corn decreased ruminal pH and increased pH variance without effect on DMI for both experiments. Fine grinding increased total tract starch and OM digestibility to a greater extent than high moisture conservation for early lactation cows. Fine grinding resulted in less daily BW loss, an increase in 3.5% FCM and milk protein content, and a decrease in microbial efficiency for the experiment after calving. Fine grinding might be more beneficial to animal production than high moisture conservation for early lactation cows.

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LIST OF ABBREVIATIONS AND SYMBOLS

A:P	acetate to propionate ratio
ADF	acid detergent fiber
ADTT	apparently digested in the total gastrointestinal tract
BCS	body condition score
BW	body weight
CP	crude protein
DM	dry matter
DMI	dry matter intake
FCM	fat correct milk
HMC	high moisture corn
INDF	indigestible NDF
DNDF	digestible NDF
NAN	nonammonia nitrogen
NANMN	nonammonia nonmicrobial nitrogen
NDF	neutral detergent fiber
OM	organic matter
OMAD	organic matter apparently digested in the rumen
OMTD	organic matter truly digested in the rumen
VFA	volatile fatty acid
TDTT	truly digested in the total gastrointestinal tract

CHAPTER 1

REVIEW OF LITERATURE

1.1 INTRODUCTION

In the eastern and midwestern U. S. corn is the most important source of starch for dairy cows. Digestibility and utilization of corn starch by dairy cattle varies widely by processing and the physiological status of animals. Corn is harvested at 25% to 35% moisture and ensiled or harvested at 5% to 20% moisture and artificially dried, if necessary to approximately 15% moisture. Storage methods commonly used for high moisture corn include packing upright silos, bags or bunkers after rolling or grinding, or storing as whole corn in oxygen-limiting silos (Soderlund, 1997). Compared with dry corn, high moisture corn allows for earlier harvest, resulting in decreased of dry matter loss in the field and elimination of fuel costs incurred during artificial drying (forced natural air system and forced heated air system). One disadvantage of utilizing high moisture corn is the loss of marketing flexibility compared with dry corn. High moisture corn must be fed to livestock and is not easily transported. Furthermore, spoilage losses might be higher than for dry corn if high moisture corn is not properly ensiled (high pH, high yeast and mold counts) or if the rate of removal from the silo is too slow to prevent spoilage.

Many methods for physically processing grain have been used to improve starch utilization. These methods usually consist of breaking, cracking, grinding, micronizing, rolling, or pelleting dried grain (Theurer et al., 1986). Hale and Theurer (1972) listed a complete description of different processing methods. Dry processing methods include grinding, dry rolling, popping, extruding, micronizing, roasting, and pelleting. Wet processing methods include soaking, steam-rolling, steam-flaking, exploding, pressure cooking, high moisture fermentation of early harvested grains, and reconstituted grains. These methods result in an increase in surface area and (or) gelatinization of starch. The extruding, roasting, and pressure-cooking processes are no longer used extensively for cereal grains. Likewise, popping, micronizing and exploding, developed during the cheap fossil fuel prices of the 1960's, are not commonly used currently. The flaking system is an extension of the steam rolling process; the moisture content of the grain is raised to approximately 18% while in the steam chamber, then the grains are run through the rollers to produce a flake, thereby, expanding the corn and completely disrupting the endosperm structure of the kernel. Theurer et al. (1986) reported most processing methods involving the application of heat and water; the degree of moisture and heat application to grain, in addition to physically decreased particle size, resulted in greater benefits than either process. Processing has different effects depending upon grain source. Theurer et al. (1986) reported that unprocessed grains with lower ruminal digestibility such as corn and sorghum respond to processing to a greater extent than barley.

Finally, starch utilization can be affected by animal factors such as level of intake, body size, and pregnancy, because of their effects on rumen retention time and site of

starch digestion. For instance, Stanley et al. (1993) reported that indigestible ADF passage increased across the prepartum period (before calving 61 d to before calving 6 d) and peaked just before calving. Postpartum indigestible ADF passage was slower than 6 d before calving, but still greater than 61 days before calving. Although differences were found in ruminal capacity, DMI and indigestible ADF passage rate, there was no effect of period on dry matter digestibility. Faichney et al. (1988) explained that despite decreased ruminal retention time, retention of digesta in the small intestine increased just before parturition. In addition, Colucci et al. (1982) found that retention time of digesta was shorter in the gastrointestinal tract with increasing intake for Holstein dairy cows. To understand starch utilization by dairy cows, the characteristics of corn starch and site of starch digestion must be understood.

1.2 CHARACTERISTICS OF CORN STARCH

The major structures of the corn kernel consist of the pericarp, horny endosperm, floury endosperm, germ and the tip cap. The pericarp, also called the hull, is the thin outer layer of the kernel that protects it from deterioration. The pericarp is resistant to water and water vapor. It also acts as a barrier to insects. The tip cap is the only area of the kernel not covered by the pericarp, and is the attachment point of the kernel to the cob. The germ (embryo) consists of essential genetic information, enzymes, vitamins and minerals for the kernel to grow into a corn plant.

The endosperm which is 82-84% of the kernel's dry weight, contains most of the starch, essential enzymes and enzyme inhibitors, and is in addition to the source of energy and protein for the germinating seed (Watson and Ramstad, 1987). Starch granules are 5-30 μm in diameter and are embedded in a protein matrix. The starch granule is composed of two main molecules: amylose and amylopectin. Amylose is a linear polymer of α -1, 4 D-glucose units (French, 1984) and amylopectin is a branched polymer with linear chains of α -1, 4 D-glucose, that contain α -1, 6 branch points every 20 to 25 glucose residues (Marshall and Whelan, 1974). Corn hybrids vary in polysaccharide composition; corn starch varies from nearly 100% amylose to nearly 100% amylopectin (Allen, 1991).

There are two types of endosperm: horny and floury. The floury endosperm surrounds the central fissure and is opaque to transmitted light. Starch availability in floury endosperm is more susceptible to grain processing (Huntington, 1997). Duvick (1961) explained that the opacity of floury endosperm is due to light refraction from minute air pockets around starch granules. These air pockets result from the tearing of thin protein matrix as it shrinks during drying, so the matrix no longer completely surrounds the starch granules, which assume a round shape. In the horny endosperm, the protein matrix is thicker and remains intact after drying. When processed, the cell walls of horny endosperm are broken but there is little release of free starch granules because of strength of protein matrix. However, the cells of floury endosperm are completely disrupted when processed, releasing free starch granules because the granules are not completely surrounded by the protein matrix (Watson and Ramstad, 1987). Beauchemin et al. (1994) reported that damage to the corn kernels during eating was sufficient to

expose the endosperm so that both the rate and extent of digestion of masticated corn were greater than half or quarter kernels.

Other factors such as corn maturity and moisture levels might affect endosperm protein and starch fractions and thus affect starch digestibility. The endosperm of a developing corn kernel is a population of cells of varying physiological ages. During kernel development, the cells in the central crown region of the endosperm begin starch accumulation first, the lower endosperm cells begin starch synthesis and accumulation much later (Boyer et al., 1977). With maturity, the hard starch layer and milk line move toward the cob and kernel sugar content declines while starch increases (Creech, 1965). As corn matures, sugars are translocated from the stover to the ear and these sugars are converted to starch. The accumulated starch is hard above the milk line but still soft below the line, therefore, making it more difficult to fracture a mature kernel because of hard starch accumulation.

The solubility of endosperm proteins can also affect starch digestion. Thornton (1976) and Stock et al. (1991) found that solubility of endosperm proteins was highly correlated with moisture level in high moisture corn and solubility increased during the length of storage. Length of storage (120, 195, 290, and 365 d after initial ensiling) was correlated positively with in vitro rate of starch digestion, and lactic acid content, and was negatively related to DM content. Their data suggested that increased fermentation and protein solubility might increase availability of starch in the rumen, which might contribute to greater acidosis problem when a large amount of high moisture corn was fed to cattle. Variation in structure of starch can be affected by processing characteristics and conservation method, which might affect starch digestibility.

1.3 SITE OF STARCH DIGESTION

Starch is fermented to volatile fatty acids in the rumen and the large intestine, or digested and absorbed as glucose in the small intestine. The rumen is the major site of starch digestion in ruminants, but with high grain diets, large quantities of dietary starch may escape ruminal fermentation and be digested postruminally. Owens et al. (1986) observed that in 40 experiments with cattle, fed between 18 and 42 % dietary starch from corn and sorghum, the range of starch digestion varied from 58% to 82% in the rumen, from 47% to 88% in the small intestine, from 33% to 66% in the large intestine, and from 88% to 98% in the whole gastrointestinal tract.

Ruminal and small intestinal digestion of starch are not completely separable. Pre-digestion in the rumen influences both the quantity and composition of starch reaching the small intestine (Owens et al., 1986). Starch appearing in the small intestine includes feed starch escaping ruminal digestion as well as microbial starch. Bacteria and protozoa contain up to 26 and 38% starch respectively, although the typical range is from 6 to 10 % (Jouany and Thivend, 1972; Hespell and Bryant, 1979). Microbial starch can account for all the starch flow to the small intestine with forage diets, but cattle fed high concentrate diets, the percentage of starch in the duodenal digestion is more than 10%. This indicates that some dietary starch must be escaping ruminal fermentation. To determine the site and extent of starch digestion by dairy cows, it is important to discuss factors affecting starch digestibility.

Ruminal starch digestibility is determined by the fractional rate constant of digestion and the total fractional rate of disappearance of starch from the rumen (the rate of digestion and passage of starch). It is important to note that digestibility is determined not only by the rate of digestion but also the rate of passage. Processing methods that increase rate of digestion such as grinding may or may not increase ruminal digestibility, depending upon their effects on rate of passage from the rumen. It is this interaction of rate of digestion and the rate of passage that determines the site of starch digestion.

1.4 RUMINAL STARCH DIGESTION

Ruminal starch degradation varies by source, moisture content, and particle size of the starch, by the animal and other dietary factors. These factors will be discussed individually, although interactions may exist. Nocek and Tamminga (1991) published that rumen degradable corn starch (% of total starch intake) ranged widely from 51% to 94% depending upon different processing methods observed from 46 experiments. When evaluated by in vitro or in situ methods, mean ruminal corn starch digestibility ranked from smallest to greatest as rolled, ground, ensiled shelled, and steam-flaked, averaging 51, 58, 72, and 87%, respectively. When evaluated in vivo, the rank of mean ruminal starch digestibility from lowest to highest was whole, cracked, ground, steam-flaked and ensiled shelled, averaging 63, 65, 76, 86 and 86%, respectively. The reviewed data are from different sources, animals, physiological status, and levels of intake.

Rate of starch digestion is related to moisture content. Aguirre et al. (1988) fed 5 cannulated steers ensiled corn which was reconstituted from dry ground corn to 15, 20, 25, 30 and 35% moisture. Starch digestibility in the rumen increased from 86.7% to 95.7% (% of total starch intake) with increasing water content from 15% to 35%. As moisture level increased, starch digestion in the small intestine also increased from 65.5% to 88.8%, starch digested in large intestine increased from 47.2% to 53.4%, and total tract starch digestibility increased from 96.7% to 99.7%.

Knowlton et al. (1996b) evaluated the effect of conservation method (high moisture vs. dry) and the effect of grinding (fine or coarse) on starch digestibility of lactating dairy cows. They reported that high moisture corn increased rumen starch digestion compared to dry corn. Total tract starch digestibility was 18.3% greater for high moisture corn than dry corn across both particle sizes, but there was a conservation method by particle size interaction since the difference between fine corn and coarse corn was greater for high moisture corn compared to dry corn. Total tract starch digestibility was 7.5 units higher for ground than coarse corn, averaged across different moisture levels, which is similar to differences for dry corn reported by Knowlton et al. (1996a). These differences in total tract digestibility among corn processing methods are less than the differences expected in ruminal starch digestibilities because of compensatory digestion in the small intestine (Firkins, 1997).

Rate of passage is affected by the animal, diet characteristics and levels of intake. Fine grinding may have less effect on rumen starch digestibility for animals with high level of intake such as dairy cattle in early lactation than for growing or fattening animals, dry cows or dairy cattle in late lactation with lower DMI (Allen and Knowlton,

1995). Allen (1997) reported that ruminal starch digestibility of ground corn was 92% with DMI at 1.32% of BW (Galyean et al., 1979), 64% for steers with DMI at 1.65% of BW (Goetsch et al., 1987), and a mean of 45% for data from four experiments with high producing dairy cows with DMI at 3.8% of BW (Cameron et al., 1991; Christensen et al., 1993; Lynch et al., 1991; McCarthy et al., 1989). Ground corn seems to be unique in its range in ruminal starch digestibility; much less variation was found within grain type for ruminal starch degradation of cracked, ensiled, steam-flaked, or whole grains (Nocek and Tamminga, 1991). Allen (1997) proposed the possible explanation for this difference in variation was fine particles of ground corn were more likely to flow from the rumen suspended in the liquid fraction than are large particles. Large differences in liquid passage rate are expected between steers at maintenance intake and dairy cattle at four times maintenance intake.

Chemicals have also been added to cereal grain to influence starch flow and digestibility. Oke et al. (1991) treated ground corn with 50% formalin (37% formaldehyde) and fed it to sheep at 50% or 75% of DMI, and found ruminal starch digestion (% of intake) was reduced 38% for formaldehyde treated corn at both levels of intake. Small intestinal starch digestibility (% of intake) was increased approximately 100% by formalin treatment. However the formalin treated corn had no effect on whole tract starch digestibility, indicating that formaldehyde treatment was effective in shifting the site of starch digestion from the rumen to the small intestine without decreasing total gastrointestinal tract starch digestion. In general, dairy cows absorb only small amounts of glucose directly from the gastrointestinal tract due to fermentation of dietary starch. Therefore, cows rely on gluconeogenesis to meet metabolic requirements for glucose.

Propionic acid and glucogenic amino acids supply glucose synthesized via gluconeogenesis. Formalin treated corn increased starch digestibility in the small intestine and improved N retention possibly by sparing utilization of amino acids for gluconeogenesis. Waldo et al. (1973) reported that formaldehyde was easy to overprotect protein supplements from rumen degradation and reduced protein digestibility. Oke et al. (1991) found that formalin treatment of corn reduced ruminal degradability of protein and increased N disappearance in the small intestine but had no effect on total tract N digestibility. This led the authors to conclude that degradation of endosperm protein affects ruminal digestibility of starch.

Diet characteristics might also affect ruminal starch digestibility. Ruminal starch digestibility was decreased when corn in diets was replaced by cottonseed hulls and corn silage (Cole et al., 1976; Brink et al., 1986). However no effect was found when corn was replaced by ground alfalfa hay (Karr et al., 1966; Tucker et al., 1968). The different effects of roughage replacement of grain may be due to the effects of roughage physical form on rate of passage.

1.5 INTESTINAL STARCH DIGESTION

Owens et al. (1986) reported that digestion of starch in the small intestine is energetically favorable. Absorption and metabolism of glucose seemed to be more efficient energetically than fermentation and absorption of organic acids because of loss of fermentation gases and heat of fermentation. This would imply an advantage to

increasing escape of starch from the rumen. Increasing ruminal starch digestion to maximize total tract digestibility and microbial protein production must be balanced with acid accumulation in the rumen and the possible loss of energetic efficiency. However, efficiency of post-ruminal digestion and absorption of starch decreases with increasing starch passage to the small intestine, as starch disappearance as a percent of that presented decreases (Nocek and Tamminga, 1991). Factors limiting starch digestion in the small intestine are activity of amylase, maltase or isomaltase due to inadequate production, non optimal enzyme activity or presence of enzyme inhibitors, absorption of released glucose from the small intestine, time for digestion and absorption of starch, and accessibility of starch in grains (Owens et al., 1986).

McCarthy et al. (1989) reported significant quantities of starch could be digested postruminally by dairy cattle in early lactation. Cows fed corn had significantly lower ruminal starch digestibility than cows fed barley (49 vs. 77%), but because of increased postruminal starch digestion for corn diet (44% vs. 19% for barley diets), whole tract digestibility of starch in the corn diet was less than 4% lower than that for the barley diet. Although many factors affect starch digestibility in the small intestine, there is evidence that digestibility might be most limited by amylolytic activity.

Two primary sources of postruminal carbohydrase activity are the pancreas and intestinal mucosa. Pancreatic amylase breaks down amylose to maltotriose and maltose. Maltase activity in the small intestine produces glucose. Complete hydrolysis of amylopectin in the small intestine requires isomaltase because pancreatic amylase has no α -1-6 glucosidic activity (Nocek and Tamminga, 1991). Harmon (1992) observed that intestinal starch digestibility in steers or heifers ranged from 17 to 85% of starch entering

the duodenum. Kreikemeier et al. (1991) infused corn starch in the abomasum of steers and recorded a decrease in disappearance from 86 to 55% as the amount of starch infused increased from 480 to 1440 g/d. Owens et al. (1986) found the similar range in their literature review. Nocek and Tamminga (1991) suggested that capacity for intestinal starch digestion in the ruminant might be limited by enzymatic hydrolysis, in particular, low amylase and inadequate isomaltose activity.

Kreikemeier et al. (1990) found that increasing feed intake increased pancreatic amylase and glucoamylase activities, small intestine length, digesta weight, and alpha-amylase activity of calves. Kreikemeier et al. (1991) also found that only about 35% of corn starch disappearing in the steer's small intestine resulted in net portal glucose absorption and suggested that other routes of disappearance are microbial fermentation to VFA and small intestine metabolism of glucose to lactate.

1.6 EFFECTS OF SITE OF STARCH DIGESTION ON ANIMAL PERFORMANCE

Glucose supplied to the mammary gland is the principal determinant of milk yield. Kronfeld et al. (1968) calculated that 72 g of glucose uptake by the mammary gland were required to produce 1 kg of milk. Therefore, abundant supplies of glucose are needed to support the requirements of mammary gland for milk lactose synthesis and also support milk protein and fat synthesis and maintenance of the mammary gland.

Increasing plasma glucose is dependent upon glucose absorbed from the small intestine or gluconeogenesis from substrates, such as propionic acid, in the liver.

Site of starch digestion might affect animal performance several ways.

Optimizing ruminal degradation of starch is important to maximize performance of dairy cattle. Insufficient ruminal degradation of starch may reduce total tract starch digestibility and impair microbial protein production. In addition, less fermentation acids are available to the animal as an energy source. However, increased rumen-escape starch decreases heat of fermentation possibly reducing heat stress in hot environments.

Excessive ruminally fermented starch results in too much VFA or lactate production in the rumen and decreases ruminal pH and microbial efficiency (Hoover and Stokes, 1991), digestibility of fiber, and DMI. Britton and Stock (1987) suggested that acidosis and rate of starch digestion and intake are closely related in feedlot cattle and that it is critical to maintain ruminal pH above 5.6 to aid in controlling subacute acidosis and maximize intake. To maximize the amount of feed fermented in the rumen per day and to have sufficient microbial efficiency, an optimal pH must be considered (Allen and Beede, 1996).

Effect of ruminal fermentability of corn starch on DMI and milk yield of dairy cows is variable. Data collected from papers from 1989 to 1997 (Table 1-1) with ruminally and duodenally cannulated dairy cows show the effects of increasing ruminal starch digestibility on DMI and FCM. Increasing ruminally degraded starch either decreased or had no effect on DMI. Studies with early lactation cows fed high moisture shelled corn or ear corn (Aldrich et al., 1993) and mid lactation cows fed barley or corn (Overton et al., 1995) found that increased ruminal starch digestibility with barley or high

moisture shelled corn decreased DMI and slightly decreased FCM. McCarthy et al (1989) reported that ruminal degraded starch increased when barley replaced corn for early lactation cows, decreasing DMI with no effect on FCM.

Several studies (Feng et al., 1993; Plascencia and Zinn, 1996; Joy et al., 1997) found that increased ruminally degraded starch had no effect on DMI but decreased FCM. Other studies reported that increased ruminal starch digestibility had no effect on DMI or FCM (Oliveira et al., 1995; Christensen et al., 1996; Knowlton et al., 1996b; Yang et al., 1997; Crooker et al., 1997).

The degree to which DMI is affected by increased ruminal starch digestibility might be due to the extent to which the increased fermentation acids are neutralized when ruminal pH is reduced. Inadequate neutralization of fermentation acids might result in a reduction in DMI which could decrease FCM production as in studies by Aldrich et al. (1993) and Overton et al (1995). When increased fermentation acids can be neutralized so that there is little or no effect on ruminal pH, FCM might not be affected as in the study by McCarthy et al. (1989). In this instance, increased microbial protein production for corn with greater available substrate might have affect decreased energy from lower DMI.

However, if DMI is not regulated by the effects of fermentation acids, increased ruminal degraded starch might depress milk fat decreasing FCM (Feng et al., 1993; Plascencia and Zinn, 1996; Joy et al., 1997). When neither DMI nor FCM were affected (Oliveira et al., 1995; Christensen et al., 1996; Knowlton et al., 1996b), fermentation acids were probably not limiting DMI and had little or no effect on milk fat content.

Differences in ruminally fermented starch affect production of fermentation acids and might affect ruminal pH, meal patterns and ultimately dry matter intake. Dry matter intake is determined by meal size and meal frequency. There is little research on the effects of corn grain processing and (or) conservation method on meal patterns, ruminal pH and DMI of dairy cattle.

1.7 CONCLUSIONS

Processing might affect both rate of digestion and rate of passage of starch which together determine ruminal digestibility. Conservation and processing methods that alter site of starch digestion might affect microbial protein production, DMI, digestibility and animal performance. Finally, increased ruminal starch digestibility might decrease DMI and have variable effects on FCM.

Therefore, the objective of this thesis was to evaluate the effects of fineness of grinding and conservation method of corn grain on ruminal and whole tract digestibility, ruminal microbial protein production and feeding behavior of Holstein heifers before and after calving. The experiment was conducted both before calving (mean DMI = 1.61% of BW) and after calving (mean DMI = 3.33% of BW) because DMI might change the relative passage rates and therefore the digestibility of the corn treatments. The hypothesis was that high moisture corn and finely ground corn would increase levels of ruminally degraded starch and total tract starch digestibility compared with field-dried corn and coarsely ground corn, thereby, increasing ruminal microbial protein production,

decreasing ruminal pH, possibly decreasing DMI and performance of early lactation dairy cows.

Table 1-1 Effect of increasing ruminal starch digestibility on DMI and FCM

Source	Lactation	DMI	Feed	RSD	DMI	FCM
Overton et al., 1995	multiparous	119	5 ratios of starch in diets from ground shelled corn and steam-rolled barley	+	-	-
Aldrich et al., 1993	multiparous	50	high moisture shelled corn vs. ear corn	+	-	-
McCarthy et al., 1989	multiparous	51	fish meal or soybean meal; corn or barley	+	-	0
Feng et al., 1993	multiparous	147	corn grain, corn cob, Hominy, and barley (high or low NSC and rapidly or slowly degraded NDF)	+	0	-
Plascencia and Zinn, 1996	primiparous	112	three densities steam-flaked corn	+	0	-
Joy et al., 1997	multiparous	131	dry corn vs. 2 densities steam-flaked corn	+	0	-
Oliveira et al., 1995	multiparous	107	steam rolled corn, dry-rolled sorghum, steam-flaked sorghum and equal mixture of steam-flaked and dry-rolled sorghum	+	0	0
Christensen et al., 1996	multiparous	30	fat w or w/o nicotinic acid based on ground shelled corn, corn silage and alfalfa haylage	+	0	0
Knowlton et al., 1996b		43	high moisture or dry corn grain, ground or coarse	+	0	0
Yang et al., 1997	multiparous	105	steam-flaked corn, barley, hull-less barley	+	0	0
Crooker et al., 1997	primiparous	55	4 ratios of dry-rolled and steam-flaked corn in diets	+	0	0

RSD = ruminal starch digestibility (% of intake)

DMI = dry matter intake (kg)

FCM = fat-corrected milk (kg)

NSC = nonstructural carbohydrate

CHAPTER 2

EFFECTS OF FINENESS OF GRINDING AND CONSERVATION METHOD OF CORN GRAIN ON RUMINAL AND WHOLE TRACT DIGESTIBILITY, RUMINAL MICROBIAL PROTEIN PRODUCTION, AND FEEDING BEHAVIOR OF HOLSTEIN HEIFERS BEFORE CALVING

ABSTRACT

The effects of fineness of grinding and conservation method of corn grain on ruminal and whole tract digestibility, ruminal microbial protein production and feeding behavior of pregnant Holstein heifers were examined. Eight ruminally and duodenally cannulated heifers were utilized in a duplicated 4×4 Latin square design balanced for carryover effects with 21-d periods. Corn treatments were dry corn, ground finely or coarsely and high moisture corn, ground finely or coarsely, prior to feeding. Diets contained 62% alfalfa silage and 36% corn grain. High moisture conservation method and fine grinding increased ruminal digestibility of starch and OM. However, mean ruminal pH was reduced and pH variance was increased with high moisture conservation only, probably because of increased ruminal VFA concentration. High moisture conservation also reduced passage of total nitrogen to the duodenum and tended to decrease microbial protein production per kg of OM fermented. Although there was no effect of treatment on DMI, high moisture conservation decreased the daily number of meals consumed. There was no effect of treatment on ruminal or total tract digestibility of NDF or ADF. Fine grinding increased total tract starch digestibility, but had no effect on total tract OM digestibility. Although both conservation method and fine grinding had large effects on ruminal starch digestibility, only high moisture conservation decreased ruminal pH, microbial efficiency, and number of meals per day for pregnant heifers.

2.1 INTRODUCTION

Corn is the most widely used cereal grain for dairy cattle diets in the eastern and midwestern US. It is harvested at high moisture (25-35% moisture) and ensiled or harvested after field drying to approximately 15% moisture. In both cases, some processing (rolling, grinding) is necessary to rupture kernels and maximize whole tract digestibility (Theurer, 1986). Site of starch digestion, which is affected by conservation method and processing (Nocek and Tamminga, 1991), can affect animal performance by altering energy available for microbial growth, forms of energy absorbed, efficiency of DE utilization, ruminal fermentation, meal patterns and DM intake. Although there is research in the literature which compares site of starch digestion across grain sources such as barley, corn, and sorghum (Oliveira et al., 1993; Grings et al., 1992; Yang et al., 1997), and processing such as grinding and steam-flaking, there are fewer data available that evaluate effects of processing high moisture corn and dry corn from the same source (Plascencia et al., 1997; Crooker et al., 1997; Joy et al., 1997). The objective of this experiment was to evaluate the effect of the conservation method (high moisture ensiled or field dry) and processing (finely or coarsely grinding) of corn on ruminal fermentation, passage of nutrients to the duodenum, meal patterns and DM intake of pregnant Holstein heifers.

2.2 MATERIALS AND METHODS

2.2.1 Corn Grain and Alfalfa Silage Harvest and Preservation

Corn grain (Great Lakes 450) was planted in one 7-acre loamy sand field at the Michigan State University's campus farm (East Lansing) on May 14, 1994. The field was divided into 12 subplots of 18 rows, 76 cm in width and 165 m in length. Alternate subplots were harvested with a 6-row combine as high moisture corn at 67.2% DM on October 5, 1994. The remaining subplots were harvested as dry corn at 83% DM on December 13, 1994 and artificially dried to 86% DM. High moisture corn was packed (Porta-Packer, Fowlerville, MI) into a silage bag (UpNorth Plastics Inc., Cottage Grove, MN) and ground finely or coarsely (Mighty Mac Chipper Shedder, Mackissic Inc., Parker Ford, PA) prior to feeding. Corn population in the field was 28,000 plants per acre. Dry corn was mixed and divided in half. One half of the dry corn was finely ground while the other half was coarsely ground at the Michigan State University feed mill, bagged and stored in a trailer throughout the experiment.

First-cutting alfalfa was ensiled in a 2.5-m diameter silage bag (50 tons; Ag Bagger®, Ag Bag Corp., Blair, NE) to minimize variation and reduce spoilage at feed out. Each load of alfalfa silage was sampled at filling and analyzed prior to the initiation of the experiment to assess variation in nutrient composition.

2.2.2 Experimental Design and Data Collection

Eight ruminally and duodenally cannulated pregnant Holstein heifers (23 months old at beginning of experiment, approximately 4 months before calving) were utilized in

a duplicated 4×4 Latin square design. Pregnant heifers were assigned to squares by expected calving date. The squares were balanced for carryover effects so that each treatment followed the other treatment an equal number of times. Within a square, each cow was assigned randomly to one of four treatment combinations. A 2×2 factorial arrangement of treatments was used in each square. Dietary treatments were corn conservation method (high moisture ensiled or field dried) and corn fineness of grinding (finely or coarsely grinding). Experimental treatment periods were 21 days, including 11 days for diet adjustment followed by 10 days of data collection. The animal care protocol was approved by All-University Committee on Animal Use and Care of Michigan State University. The approved animal use form number was 06/95-088-00.

Heifers were ruminally and duodenally cannulated 45 days prior to the start of the experiment. Duodenal cannulas were T-shaped and fabricated from a Teflon fluorocarbon polymer (Ankom Technology Corporation, Fairport, NY). Surgical placements of the cannulas were between ribs 10 and 11 as described by Robinson et al. (1985). The ruminal and duodenal cannulation surgeries were performed at the Department of Large Animal Clinical Science, College of Veterinary Medicine, Michigan State University. Cows were hospitalized until they recovered from the surgical procedure.

Diets consisted of alfalfa silage, dry or high moisture corn, soybean meal, minerals and vitamins for each treatment period (Table 2-1 and 2-2; values represent mean ingredient and nutrient composition throughout the experiment). The diets were balanced to 31% NDF, 39% starch and 15% crude protein. Minerals and vitamins were included with soybean meal as a premix to meet requirements (NRC, 1989). High moisture corn was ground prior to feeding through a mill without (coarse) or with (fine) a 1 cm screen (Mighty Mac Chipper Shedder, Mackissic Inc., Parker Ford, PA). Five alfalfa silage samples from different sites of the silage bag were analyzed for DM, NDF

and crude protein, and the average values were used for diet formulation for the experiment.

Alfalfa silage, corn treatments and protein-mineral-vitamin premix were weighed into individual polyethylene mangers for each cow and thoroughly mixed by hand. Cows were fed once daily at 1400 h at 110% of expected intake. Ration offered was recorded for each cow, and weights oforts were recorded prior to each feeding. Dry matter intake was calculated as the average daily DMI from d 13 to d 21 of each period. Dietary ingredients (0.5 kg) and individual cow orts (12.5% of orts as wet weight basis) were collected daily during the collection period, frozen and composited within each collection period. Alfalfa silage was analyzed weekly for DM content during the experiment and diets were re-balanced accordingly.

Cows were housed in tie stalls bedded with chopped newspaper and were exposed to continuous light throughout the experiment. Rumen empty body weights (BW) were measured on the last 2 days of each period and on 2 days preceding the first period. Body condition score (BCS) was evaluated to the quarter point on a five-point scale (1 = thin to 5 = fat) on d 20 of each period and 2 days prior to beginning the first period.

Duodenal flow was estimated using a double marker system (Faichney, 1980) with Cr-mordanted wheat straw NDF as a particulate phase marker and Co-EDTA as a liquid phase marker. Chromium-mordanted NDF and Co-EDTA were prepared as described by Udén et al. (1980). Chromium mordanted wheat straw was ground through a Wiley mill (2 mm screen; Arthur H. Thomas, Philadelphia, PA) and the chromium-mordanted NDF was provided at approximately 0.14% of DM intake (30 g/d per cow). Chromium content of the fiber was approximately 5% of DM resulting in a Cr intake of 1.6 g/d per cow. Gelatin capsules (1.5 Oz, Tropac Inc., Airfield, NJ) filled with chromium mordanted wheat straw were dosed into the rumen 2 times/d from d 11 until d 19 at 0730 and 1930 h. Co-EDTA (0.43 g Co/d, 0.91g Co/l solution) was dosed at approximately 0.04% of DMI by semi-continuous infusion into the rumen by a peristaltic

pump (FPU101, Omegaflex™ peristaltic pump, Omega Engineering Inc., Stamford, CT). Pumps had a flow rate of 3.3 ml/min but were turned on intermittently for 1 min of every 10 min to achieve an average flow rate 0.33 ml/min over the 9 days (475 ml Co-EDTA solution/d, 0.43 g Co/d). A priming dose of each marker was given on d 10 of the 21-d period at 3 times the daily dose.

For determination of ruminal and total tract nutrient digestibility, duodenal digesta and feces were taken every 3 h beginning at 1400 h on d 16 and continuing until at 1300 h on d 19. The sampling time was adjusted ahead 1 h daily, so that 24 samples representing each hour in a day were collected. Two separate samples of duodenal digesta were collected (300 ml and 40 ml). The 300 ml samples were frozen immediately at -20°C until analysis and the 40 ml samples were preserved with 3 ml of 6 N HCl and frozen for later analysis of NH_3 . Fecal samples (400 g) were collected and frozen immediately at -20°C until analysis.

Samples of ruminal fluid were collected every 3 h of a 24-h period starting at 1400 h on d 16 to account for diurnal effects on concentration of metabolites. Samples of rumen fluid from five sites in the rumen were mixed and filtered through 4 layers of cheesecloth to remove particulate matter. Three 40 ml subsamples of ruminal fluid were taken from this sample for each period. One was preserved with 3 ml of 6 N HCl for NH_3 analysis, one was preserved with 3 ml 20% NaOH for volatile fatty acids (VFA) and lactate analysis, and one was taken for purine analysis. All subsamples were frozen (at -20°C) immediately following collection.

Rumen digesta were manually evacuated from each cow at 0800 h on d 20 (6 h prefeeding) and 2000 h on d 21 of the experiment period (6 h postfeeding). A 10% aliquot of digesta was separated during evacuation for ease of subsampling and measuring liquid and solid phases. This aliquot was weighed, mixed by hand and strained through four layers of cheesecloth to separate into solid and liquid phases. Solid phase samples were weighed and subsampled, and a 400 g solid sample was frozen for

determination of DM and nutrient composition. Three separate subsamples (300 ml, 40 ml, and 40 ml) of rumen liquid were collected. The 300 ml samples were frozen (-20°C) immediately for DM, NDF, ADF, acid detergent sulfuric acid-lignin, starch and indigestible NDF analysis, while the 40 ml subsamples of ruminal fluid were preserved with 3 ml of 6 N HCl and frozen (-20°C) for later NH₃ analysis, and the 40 ml subsamples of rumen fluid were preserved with 3 ml of 20% NaOH and frozen (-20°C) for later VFA and lactate analysis. Rumen total digesta weights and volumes were measured at each evacuation.

Feed disappearance, chewing behavior and ruminal pH were measured continuously for 4 days from d 12 to d 15 of each experimental period using a computerized data acquisition system described by Dado and Allen (1993). Data was written to files every 5 seconds for each variable, for each cow. Chewing monitors were fitted to cows 1 day prior to collection to allow for cow adaptation and remained in place throughout the behavior collection period. There were no other cows present in the barn during the study. Load cells for determination of feed consumption were calibrated prior to each collection period. Electrodes for pH determination (described by Knowlton et al., 1996a) were calibrated daily immediately before feeding. Electrodes generally held their calibration within 0.05 pH units. Electrodes outside this range were recalibrated or replaced. Occasional problems with jaw movement detectors, load cells and pH electrodes were recorded. Additionally, the cows feeding behavior data for the entire day were removed from the data file prior to analysis. Water intake was recorded daily from water meters at each stall (Omega MKH 4465 5/8, Omega Engineering Inc., Stamford, CT).

2.2.3 Analysis of Samples

Samples of each corn treatment were taken daily from d 13 until d 21 of each period for particle size analysis. A representative sample of each corn treatment was dry sieved through 8 sieves (Sieve apertures: 4750, 2360, 1180, 600, 300, 150, 75 μm and bottom pan), using a sieve shaker (Model RX-86, W.S. Tyler Inc., Gastonia, NC) for approximately 15 min until the bottom pan weight was constant (ASAE, 1968). Mean particle size of corn was calculated and variance was determined by fitting the data to a gamma distribution (Allen et al., 1983).

Diet ingredient and orts samples were analyzed for DM, ash, NDF, ADF, acid detergent sulfuric acid-lignin, starch, CP and indigestible NDF. The samples were dried in a forced air oven at 55°C for 72 hours and analyzed for DM content. All samples were ground with a Wiley mill (1 mm screen; Arthur H. Thomas, Philadelphia, PA). Ash was determined following sample ignition at 500°C for 5 hours. Samples were analyzed sequentially for NDF (procedure A, Van Soest et al., 1991), ADF (AOAC, 1984) and acid detergent sulfuric acid-lignin (Goering and Van Soest, 1970). Crude protein was analyzed according to Hach et al. (1987). Indigestible NDF was estimated as NDF content of sample following in vitro fermentation in buffered rumen media for 120 hours (Goering and Van Soest, 1970). Starch was analyzed by a one-stage enzymatic method of glucoamylase (Diazyme L-200, Miles, Inc., Elkhart, IN) with a NaOH gelatinization step (O'Neil et al., 1993). Following gelatinization the sample was centrifuged at 26,000 $\times g$ for 20 min. Concentration of glucose in the supernatant was analyzed by HPLC using an Aminex fast carbohydrate column (100 $\times$ 7.8 mm, catalog number 125-0105; Bio-Rad Laboratories, Richmond, CA). Column temperature was 85°C, and the solvent was degassed deionized distilled H₂O with a flow rate of 0.6 ml/min. Detection was by refractive index (Waters 410, Millipore Corp., Milford, MA). Concentration of all

nutrients except DM was expressed as a percentage of DM determined from forced air oven drying at 105°C.

Daily frozen duodenal samples ($n = 8$) were chopped and subsampled on an equivalent wet weight basis, lyophilized and ground with a mortar and pestle. Duodenal digesta was analyzed for DM, NDF, ADF, acid detergent sulfuric acid-lignin, ash, CP, starch and indigestible NDF as previously described and purine analysis as described later. Fecal samples were thawed, subsampled and composited on an equivalent wet weight basis for each cow per day. Then, samples were dried in a forced air oven at 55°C for 72 hours and analyzed for DM content. Fecal samples were ground with a Wiley mill (1 mm screen) and analyzed for DM, NDF, ADF, acid detergent sulfuric acid-lignin, ash, CP, starch and indigestible NDF as described previously.

For analysis of flow markers, daily frozen duodenal samples were chopped into snow using a food processor (84142 Food cutter, Hobart Manufacturing Co., Troy, OH), subsampled on an equal wet weight, thawed and partitioned into liquid and solid phases by centrifuge (RC5C, Sorvall Instrument, E. I. du Pont de Nemours & Co., Inc., Hoffman Estates, IL) at $500 \times g$ for 10 min at 4°C. Each phase of sample was dried in a 100°C forced air oven for later chromium and cobalt analysis. Chromium and cobalt concentration of feeds, duodenal liquid phase, duodenal solid phase and feces were determined by atomic absorption spectrometry according to the manufacturers' recommendations (Smith-Hieftje 4000, Thermo Jarrell Ash Co., Franklin, MA) following digestion with a phosphoric acid-manganese sulfate solution (Williams et al., 1962). Duodenal digesta flow was calculated as described by Armentano and Russell (1985).

Ruminal samples for purine analysis were prepared following the procedure of Overton et al (1995). Purines were measured (Zinn and Owens, 1986), modified by Overton et al. (1995) as a bacterial marker. Microbial protein production was calculated by dividing purine to nitrogen ratio of ruminal microbes by purine percentage of duodenal DM per day (Zinn and Owens, 1986).

Duodenal and ruminal samples for NH_3 analysis were thawed and composited on an equivalent volume basis for each cow per day. Ammonia was measured using the general procedure of McCullough (1967), modified by Broderick and Kang (1980). Absorbance was determined using a spectrophotometer (1 cm length path, DU-64 Spectrophotometer, Beckman Instruments, Inc., Fullerton, CA).

Ruminal fluid samples were thawed and composited on an equivalent volume basis for each cow per day for VFA and lactate analysis. Composite rumen fluid samples were centrifuged at $26,000 \times g$ for 30 min. Concentrations of VFA and lactate of supernatant were determined by HPLC as described by Dado and Allen (1995).

Ruminal solid and liquid subsamples from the evacuated rumen digesta were dried in a 100°C forced air oven, and analyzed for DM, NDF, ADF, acid detergent sulfuric acid-lignin, ash, starch, and indigestible NDF as described previously. Ruminal liquid subsamples were analyzed for NH_3 and VFA as described previously. Ruminal pool sizes (kg) of DM, liquid, NDF, starch and indigestible NDF were calculated by multiplying the concentrations of each by the ruminal digesta weight (kg).

Ruminal starch and NDF turnover time were determined by dividing the pool size of starch or NDF by hourly starch or NDF intake. Rates of starch, indigestible NDF (INDF) and potentially digestible NDF (DNDF) passage from the rumen were determined by dividing starch or INDF or DNDF daily outflow to duodenum (OUTFLUX, dual markers system) by the pool size of starch, or indigestible NDF or digestible NDF. Rate of digestion of starch or DNDF was calculated by the reciprocal of the turnover time (equal to rate of digestion and rate of passage) minus rate of passage of starch or DNDF. Rate of INDF passage from the rumen (INFLUX, internal marker system) was determined by the method of Dado and Allen (1995) by dividing the rumen pool size of INDF into hourly intake of INDF. Estimated rate of water passage from the rumen was calculated, as duodenal flux of water divided by the pool size of water in the

rumen. This calculation assumes no net water absorption prior to the duodenum and that Co-EDTA passes at the same rate as water.

Mean ruminal pH, hours below pH 5.5 and 6.0, and the areas of the pH $\times$ time curve under pH 5.5 and 6.0 (Mackie and Gilchrist, 1979) were calculated. The area of the pH $\times$ time curve below a critical pH gives a weighted average of the deviation from this pH which is more meaningful to optimal ruminal pH (Allen and Beede, 1996).

For feeding behavior data analysis, means were calculated for number of meals per day, meal size (kg per meal), minutes between meals, eating time in minutes per meal and per day, eating chews per meal and per day, eating chew rate (chews per minute), number of ruminating bouts per day, minutes between ruminating bouts, ruminating time in minutes per bout and per day, ruminating chews per bout and per day, ruminating chew rate and total chewing per day (eating chews and ruminating chews) using a program written in SAS programming language (Version 6.1, SAS Institute Inc., Cary, NC).

2.2.4 Statistical Analysis

Data were analyzed using the fit model procedure of JMP (Version 3.2, SAS Institute Inc., Cary, NC) as duplicated ($n = 2$) 4×4 Latin squares using the following model:

$$Y_{ijkl} = \mu + S_i + C_{j(i)} + P_k + T_l + ST_{il} + SP_{ik} + E_{ijkl}$$

where

μ = overall mean,

S_i = random effect of square ($i = 1$ to 2),

$C_{j(i)}$ = random effect of cow within square ($j = 1$ to 4),

P_k = random effect of period ($k = 1$ to 4),

T_l = fixed effect of treatment ($l = 1$ to 4),

ST_{il} = interaction of square and treatment,

SP_{ik} = interaction of square and period, and

E_{ijkl} = residual, assumed to be normally distributed.

A reduced model without square $\times$ treatment or square $\times$ period interactions was used when these effects were not significant ($P > 0.10$). Preplanned orthogonal contrasts were used to determine significance of the main treatment effects of the conservation method, fineness of grinding and their interaction. Main effects and interactions were declared significant at $P < 0.05$, and $P < 0.10$, respectively.

2.3 RESULTS AND DISCUSSION

2.3.1 Composition of Diets and Particle Size of Corn Grain

Chemical composition of the corn treatments appears in Table 2-1. Except for the expected effect of conservation method on DM content, only slight differences in composition were detected among treatments. High moisture conservation method had a very slight effect on percentage of organic matter percent for corn by increasing OM percentage by 0.15 units of DM. Dry corn had higher NDF content than high moisture corn (10.7 vs. 8.1% of DM). Finely ground corn tended to have higher starch content than coarse corn ($P = 0.07$). Diets contained 62% alfalfa silage and 36% corn grain (Table 2-2). Diets containing high moisture corn had lower DM (47.1 vs. 50.7%) and NDF (30.8 vs. 31.7 % of DM) than diets containing dry corn. Remaining nutrients measured in diets did not differ by treatment.

Mean particle size of dry fine corn, dry coarse corn, high moisture fine corn and high moisture coarse corn was $771 \pm 56 \mu\text{m}$, $4524 \pm 170 \mu\text{m}$, $1933 \pm 157 \mu\text{m}$ and $5526 \pm 461 \mu\text{m}$, respectively. Field dried conservation and fine grinding decreased particle size of corn ($P < 0.01$, Table 2-1). Because moisture contents for field dried conservation and high moisture conservation were different, they were processed with different mills. There were similar reductions in particle size by fine grinding dry corn and high moisture corn (Figure 2-1).

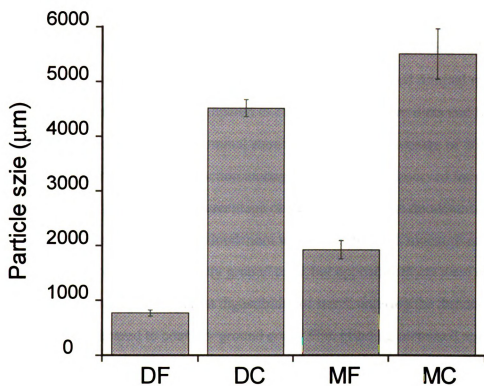


Figure 2-1 Particle size mean and standard deviation for four corn grains

DF: dry fine, MF: high moisture fine, DC: dry coarse, MC: high moisture coarse.

2.3.2 Nutrient Digestibility

Apparent ruminal starch digestibility was higher for fine grinding and for high moisture conservation (Table 2-3). Grinding corn finely increased ruminal starch digestibility an average of 46% compared to coarsely ground corn diets and high moisture conservation increased ruminal starch digestibility an average of 36% compared to field dried corn diets. An interaction among treatments was observed for post-ruminal apparent starch digestibility as a percentage of starch entering the duodenum. Apparent digestibility of starch entering the duodenum was higher for high moisture coarsely ground corn compared to with finely ground corn, but opposite effects were observed for dry corn which had higher apparent digestibility of starch entering the duodenum for finely ground compared to coarsely ground corn. Fine grinding increased apparent digestibility of starch in the total tract from 93.4% to 96.8% ($P < 0.01$, Table 2-3). Conservation method had no effect on apparent total tract starch digestibility. Additionally, the increased ruminal starch digestibility with corn grain processing and high moisture conservation agrees with a previous study with lactating cows (Knowlton et al., 1996b). Grinding breaks floury and horny endosperm of corn kernels to release starch granules thereby increasing rate of starch degradation. The ratio of starch apparently digested in the rumen to that digested post ruminally was over 4-fold higher for the finely ground high moisture corn, and 2-fold higher for the finely ground dry corn diets compared with their respective coarse corn diets. There was a significant interaction, which was due to the greater difference between finely and coarsely grinding for the high moisture corn diets compared to dry corn treatment (Table 2-3).

Ruminal and total tract digestibilities of NDF and ADF were not affected by treatment (Table 2-4). Fine grinding decreased post-ruminal NDF digestibility by 25% compared to coarse corn diets, although the difference had no effect on total tract NDF

digestibility. This might have been due to increased substrate available for microbial growth in the large intestine, resulting in increased NDF digestibility for coarse corn diets compared with finely ground corn treatment. However, Grant and Mertens (1992) reported that addition of starch decreased in vitro NDF digestibility because of decreased rate of digestion and increased lag time by additional starch.

There were no treatment differences observed for apparent total tract DM or OM digestibility in spite of large treatment differences for OM digestibility in the rumen (Table 2-3). Apparent digestibility of OM in the rumen increased from 37.4% in dry corn diets to 46.1% for high moisture corn diets ($P < 0.01$). Apparent digestibility of OM in the rumen increased from 37.3% for coarse corn diets to 46.1% for fine corn diets ($P < 0.01$). High moisture conservation and fine grinding increased the true ruminal digestibility of OM, but a significant interaction was detected indicating that fine grinding increased true OM digestibility to a greater extent for high moisture corn correlated to dry corn. The amount of OM passage to duodenum and postruminal OM digestibility, expressed as a percentage of OM intake were decreased 24.4% and 26.5% lower, respectively, as high moisture corn compared to dry corn and finely ground corn compared to coarsely ground corn. High moisture conservation and fine grinding also decreased postruminal OM digestibility expressed as a percentage of OM entering the duodenum, but a significant interaction indicated that the decrease was much greater for cows fed high moisture corn diets. Greater postruminal OM digestibility compensated for lower ruminal OM digestibility for dry and coarse treatments resulting in no effect of treatment on whole tract OM digestibility.

2.3.3 Rumen Pool Size, Passage of Indigestible NDF and Starch, Ruminal pH and Volatile Fatty Acids

There was no effect of treatment on ruminal pool size of liquid, DM, digesta volume, digesta weight or digesta density (Table 2-5). However, significant interactions of treatment were detected for pool sizes of NDF, indigestible NDF and starch, as well as NDF and starch turnover time, indigestible NDF rate of passage, and rate of digestion of potentially digestible NDF. Ruminal turnover time and pool size of starch increased for coarsely ground corn for both conservation methods, but a significant interaction indicated that the increase was much greater for dry corn. The increase in turnover time and pool size was due to a slower rate of digestion. Field dry conservation decreased starch rate of digestion an average of 38% lower compared with high moisture conservation. Grinding corn coarsely decreased starch rate of digestion an average of 34% lower compared to finely ground corn diets. Cows fed high moisture fine corn diets had fastest rate of digestion and lowest rate of passage compared with the other three treatments. Rate of digestion was much lower for the dry coarse corn diet, probably because of the lower surface area available for enzymatic attack and lower solubility of endosperm proteins, reducing access of microbes to starch granules (Oke et al., 1991).

Ruminal turnover time and pool sizes of NDF and indigestible NDF increased for coarsely ground corn that was field dried compared to finely ground dry corn, but decreased for coarsely ground corn conserved as high moisture corn compared with finely ground high moisture corn. This might be due to decreased rate of passage of INDF (outflux) for coarse dry corn compared with finely ground dry corn. Moreover,

coarse grinding increased rate of passage of INDF (outflux) compared to fine grinding for high moisture corn. Although there was no effect of treatment on rate of passage of INDF (influx), the numerical differences were similar to the effects of treatment on rate of passage of INDF (outflux). An interaction was observed for rate of digestion of digestible NDF with a faster rate of digestion for fine dry corn compared to coarse dry corn, but slower rate of digestion for fine high moisture corn compared with coarse high moisture corn. There is no obvious explanation for this. Meanwhile, there was no effect of diet on water passage calculated with this method.

High moisture conservation decreased daily mean pH in the rumen and increased pH variance but had no effect on pH range, hours below pH 6.0 or 5.5, or area below pH 6.0 or 5.5 (Table 2-6). Furthermore, particle size processing had no effect on ruminal pH. For finely ground corn diets, the assumed increase in fermentation acid production from greater ruminal OM digestibility apparently was buffered adequately in the rumen to prevent a decrease in ruminal pH. Fine grinding tended to decrease the ammonia N concentration in the rumen an averaging 12.1% less than coarsely ground corn treatments ($P = 0.10$, Table 2-6).

High moisture conservation increased total volatile fatty acids (VFA) concentration in the rumen an average of 5% higher compared with dry corn diets (Table 2-6), which corresponded to a decreased of daily mean ruminal pH by 0.10 units. High moisture conservation decreased the molar proportion of propionate of VFA an average of 6.6% lower and increased the ratio of acetate to propionate an average of 9.1% higher compared with dry corn treatments. The decreased in the proportion of propionate and the increased in the ratio of acetate to propionate was larger for the finely ground corn as

indicated by significant interactions of treatments. An interaction was observed for acetate as a percentage of VFA with a higher percentage of acetate for dry fine corn compared to dry coarse corn and a lower percentage of acetate for high moisture fine corn compared with high moisture coarse corn. There is no effect of fine grinding on total VFA concentration and individual acid proportions. A significant interaction of treatments was found for formate as a percentage of VFA with a greater percentage for dry coarse corn compared with dry fine corn and a lower formate as a percentage of VFA for high moisture coarse corn compared to high moisture fine corn. Lactate in the rumen was not detected.

2.3.4 Intake and Feeding Behavior Data

Treatment differences were not detected for DMI, DMI as a percentage of BW, or change in BW or BCS (Table 2-7). DMI as a percent of BW averaged 1.63% for pregnant heifers. Although no effect of treatment was observed for DMI, dry corn treatment resulted in an increase in the number of meals consumed per day (Table 2-8). There was no effect of treatment on meal size or length, eating time or intermeal interval. However, there was an interaction of treatment for eating rate with a faster eating rate for fine dry corn compared to coarse dry corn and a slower eating rate for fine high moisture corn compared to coarse high moisture corn. An interaction was observed for the number of chews per meal and per day with a greater number of chews for coarse dry corn compared to fine dry corn and fewer chews for coarse high moisture corn compared with

fine high moisture corn. The reasons for these two interactions are not apparent. Chewing rate during eating tended ($P = 0.07$) to be lower for the high moisture corn treatments compared to field dried corn treatments, which might be because of softer kernel for high moisture corn. There was no effect of treatment on rumination activity, total chewing activity or daily water intake.

2.3.5 Microbial N Production and N Flow to the Duodenum

Intake of N averaged 194 g/d and was not affected by treatment (Table 2-9), but the amount and proportion of total N, nonammonia nitrogen (NAN) and nonammonia nonmicrobial nitrogen (NANMN) passed to the duodenum were significantly lower for high moisture corn diets than dry corn diets ($P < 0.05$). Postruminal N digestibility (% of intake) was an average of 9.4% lower for high moisture corn diets compared with dry corn diets ($P = 0.03$). However, apparent total tract digestibility of N was not affected by high moisture conservation. Fine grinding tended to decrease total tract N digestibility and decreased passage of NANMN compared to coarsely ground corn treatment.

Additionally, there was no effect of fine grinding on passage of total N, NAN (nonammonia nitrogen), microbial N and postruminal N digestibility. NANMN includes by-pass protein, peptides, amino acids from feed and endogenous protein. High moisture conservation method and fineness of grinding reduced the amount and proportion of passage of NANMN, and also there was an interaction observed because of a larger decrease for fine grinding when cows fed high moisture corn diets, indicating that high

fermentation diets (high moisture corn) had more protein degraded in the rumen. Although the amount of microbial N was not affected by treatment, the percentage of microbial N in the NAN was higher for high moisture corn compared with dry corn and finely ground corn compared to coarsely ground corn. A significant interaction of treatments indicated that the increase was much greater for high moisture corn diets. Efficiency of microbial protein synthesis expressed as grams of microbial N per kilogram of OM either apparently or truly digested in the rumen tended to decrease by high moisture conservation method. McCarthy et al (1989) reported the amount of microbial N passed to duodenum was not affected by quickly fermented barley compared to corn, which agrees with this data that quickly fermented ground or high moisture corn had no effect on the amount of microbial N passed to duodenum. High moisture conservation decreased microbial efficiency an average of 16% (Table 2-9) but increased true ruminal digestibility of OM an average of 15% higher (Table 2-3), which resulted in no effect of high moisture conservation on total tract digestibility of OM.

2.4 CONCLUSIONS

High moisture conservation and fine grinding increased both apparent and true ruminal OM and starch digestibility, but had no effect on total tract OM digestibility. Total tract starch digestibility was reduced by fine grinding, only. The higher ruminal starch digestibility for high moisture corn and finely ground corn was due to increased rate of starch digestion. High moisture corn decreased mean daily ruminal pH and increased variance in ruminal pH, and although decreased the daily number of meals

consumed, it had no effect on DMI. Additionally, high moisture conservation reduced passage of total nitrogen to the duodenum and tended to decrease microbial protein production per kg of OM fermented. There was no effect of treatment on ruminal or total tract digestibility of NDF or ADF.

Although high moisture conservation method and fine grinding had similar positive effects on ruminal digestibilities of starch and OM with negative effects on postruminal digestibilities of OM and starch, only high moisture conservation method decreased ruminal pH, microbial efficiency, and number of meals per day for pregnant heifers. Fine grinding might be more advantageous than high moisture conservation to increase ruminal starch digestibility of corn grain fed to heifers.

TABLES

Table 2-1 Chemical composition and particle size of corn grain

	Corn grain treatments ¹				P = ²	
	DF	DC	MF	MC	C	C x G
Chemical composition						
55°C DM, %	87.3	87.5	64.3	64.8	<0.01	NS
OM, % of DM	97.9	97.9	98.0	98.0	0.02	NS
CP, % of DM	9.6	9.6	9.3	9.4	NS	NS
NDF, % of DM	11.0	10.5	8.1	8.1	<0.01	NS
ADF, % of DM	2.9	2.6	2.6	2.4	NS	NS
Lignin, % of DM	1.2	0.8	0.8	0.7	NS	NS
Indigestible NDF, % of DM	2.6	2.3	2.0	1.8	0.02	NS
Starch, % of DM	78.6	76.2	77.1	76.5	NS	NS
Particle size mean (µm)	771	4524	1933	5526	<0.01	NS

¹ Corn grain treatments: DF = dry fine, DC = dry coarse, MF = high moisture fine, MC = high moisture coarse .

² C = Main effect of conservation method; G = Main effect of fineness of grinding; C x G = Interaction of C and G.

Table 2-2 Ingredient and chemical composition of diets.

	Treatment ¹				P =		
	DF	DC	MF	MC	C	G	C x G
Ingredients, % DM of diet							
Alfalfa silage ²	62.0	62.0	62.4	62.2			
Dry corn							
Fine	36.2	-	-	-			
Coarse	-	36.2	-	-			
High moisture corn							
Fine	-	-	35.7	-			
Coarse	-	-	-	35.9			
Protein-mineral-vitamin mix ³	1.9	1.9	1.9	1.9			
Chemical composition							
55°C DM, %	50.7	50.7	47.1	47.2	< 0.01	NS	NS
OM, % of DM	93.5	93.5	93.5	93.5	NS	NS	NS
CP, % of DM	14.9	14.9	14.8	14.9	NS	NS	NS
NDF, % of DM	31.7	31.7	30.8	30.8	< 0.01	NS	NS
ADF, % of DM	21.6	21.5	21.6	21.5	NS	NS	NS
Lignin, % of DM	6.5	6.4	6.5	6.3	NS	NS	NS
Indigestible NDF, % of DM	18.7	18.5	18.5	18.5	NS	NS	NS
Starch, % of DM	39.2	38.4	38.3	38.2	NS	NS	NS

¹ Treatment: DF = dry fine, DC = dry coarse, MF = high moisture fine, MC = high moisture coarse.

² Alfalfa silage composition: 40.3% DM at 55°C. Each of the following were measured as a percentage of DM: 44.2% NDF, 32.9% ADF, 8.1% lignin, 17.5% CP, and 16.5% starch.

³ Protein-mineral-vitamin mix contained 83.0% soybean meal 44, 13.2% salt, 3.8% Akey TM #38-600 (vitamin and trace mineral supplements). Protein-mineral-vitamin mix composition: 91.2% DM at 55°C. Each of the following were measured as a percentage of DM: 21.4% NDF, 6.5% ADF, 0.85% lignin, 31.4% CP, and 25.2% starch.

Table 2-3 Effect of treatment on intakes and digestibilities of DM, OM, and starch

	Treatment				P =		
	DF	DC	MF	MC	C	G	C x G
DM							
Intake, kg/d	7.6	7.9	7.6	7.7	NS	NS	NS
ADTT, kg/d	5.7	6.0	5.7	5.9	NS	NS	NS
digestibility, % of Intake	75.0	75.1	75.0	75.2	NS	NS	NS
OM							
Intake, kg/d	7.1	7.4	7.1	7.2	NS	NS	NS
Apparently digested in the rumen							
kg/d	2.9	2.7	3.9	2.9	0.02	0.01	NS
digestibility, % of Intake	39.7	35.0	52.5	39.6	< 0.01	< 0.01	NS
Truly digested in the rumen							
kg/d	4.6	4.2	5.7	4.4	0.02	< 0.01	0.09
digestibility, % of Intake	64.6	57.5	79.2	61.3	< 0.01	< 0.01	0.05
Passage to duodenum, kg/d	4.2	4.7	3.1	4.3	< 0.01	< 0.01	NS
Apparently digested postruminally, kg/d	2.5	3.0	1.5	2.6	< 0.01	< 0.01	NS
digestibility, % of Intake	35.2	40.5	21.1	36.1	< 0.01	< 0.01	NS
% of entering duodenum	59.5	63.8	48.4	60.5	< 0.01	< 0.01	0.02
ADTT							
kg/d	5.4	5.7	5.4	5.5	NS	NS	NS
digestibility, % of Intake	75.8	76.1	76.1	76.3	NS	NS	NS
Starch							
Intake, kg/d	3.1	3.1	3.0	3.0	NS	NS	NS
Apparently digested in the rumen							
kg/d	1.7	1.2	2.4	1.5	0.02	< 0.01	NS
digestibility, % of Intake	56.6	41.7	81.4	52.7	0.02	< 0.01	NS
Passage to duodenum, kg/d	1.4	1.9	0.6	1.5	< 0.01	< 0.01	NS
Apparently digested postruminally, kg/d	1.3	1.7	0.5	1.3	< 0.01	< 0.01	NS
digestibility, % of Intake	41.9	54.8	16.7	43.4	< 0.01	< 0.01	NS
% of entering duodenum	92.9	89.5	83.3	86.7	< 0.01	< 0.01	0.02
Ratio of % digested in rumen to postrumen	1.31	0.71	4.79	1.15	< 0.01	< 0.01	0.01
ADTT							
kg/d	3.0	2.9	2.9	2.8	NS	NS	NS
digestibility, % of Intake	96.8	93.5	96.7	93.3	NS	< 0.01	NS

Table 2-4 Effect of treatment on intakes and digestibilities of NDF and ADF

	Treatment ¹				P = ²	
	DF	DC	MF	MC	C	G
NDF						
Intake, kg/d	2.4	2.4	2.4	2.4	NS	NS
Truly digested in the rumen						
kg/d	0.9	0.8	0.8	0.8	NS	NS
digestibility, % of Intake	31.1	32.9	26.6	27.9	NS	NS
Passage to duodenum						
kg/d	1.5	1.6	1.6	1.6	NS	NS
Truly digested postruminally, kg/d	0.3	0.4	0.3	0.4	NS	NS
digestibility, % of Intake	12.5	16.6	12.5	16.6	NS	NS
% of entering duodenum	20.0	25.0	18.8	25.0	NS	NS
TDTT ³						
kg/d	1.2	1.2	1.1	1.2	NS	NS
digestibility, % of Intake	46.0	48.4	45.6	46.5	NS	NS
ADF						
Intake, kg/d	1.6	1.6	1.7	1.6	NS	NS
Truly digested in the rumen						
kg/d	0.6	0.7	0.6	0.6	NS	NS
digestibility, % of Intake	34.4	36.2	28.9	33.7	NS	NS
Passage to duodenum						
kg/d	1.0	1.0	1.1	1.0	NS	NS
Truly digested postruminally, kg/d	0.2	0.2	0.2	0.2	NS	NS
digestibility, % of Intake	12.5	11.8	12.5	12.5	NS	NS
% of entering duodenum	20.0	20.0	18.2	20.0	NS	NS
TDTT ³						
kg/d	0.8	0.8	0.8	0.8	NS	NS
digestibility, % of Intake	48.7	48.7	47.4	48.0	NS	NS

¹Treatment: DF = dry fine, DC = dry coarse, MF = high moisture fine, MC = high moisture coarse.

²C = Main effect of conservation method; G = Main effect of fineness of grinding; C x G = Interaction of C and G.

³TDTT = truly digested in the total tract.

Table 2-5 Effect of treatment on ruminal passage, digestion and pool sizes

	Treatment ¹				P = ²		
	DF	DC	MF	MC	C	G	C x G
Rumen parameters							
Water passage, %/h	4.9	5.6	6.2	5.6	NS	NS	NS
Starch turnover time, h	2.8	4.3	3.0	3.1	0.07	<0.01	0.02
Starch rate of passage, %/h	16.0	13.9	9.3	12.0	0.04	NS	NS
Starch rate of digestion, %/h	21.6	9.8	27.5	22.8	0.04	0.09	NS
NDF turnover time, h	32.8	34.9	38.4	30.5	NS	NS	0.09
INDF (influx) rate of passage ³ , %/h	2.3	2.1	2.2	2.3	NS	NS	NS
INDF (outflux) rate of passage ⁴ , %/h	2.1	1.9	2.0	2.5	0.05	NS	0.01
DNDF rate of passage ⁵ , %/h	2.0	2.3	2.2	1.9	NS	NS	NS
DNDF rate of digestion ⁶ , %/h	6.7	4.7	5.7	7.2	NS	NS	0.09
Digesta volume, l	51.7	55.9	50.9	51.9	NS	NS	NS
Digesta wt, kg	43.9	45.8	43.8	44.1	NS	NS	NS
Digesta density (kg/l)	0.85	0.82	0.86	0.85	NS	NS	NS
Rumen pool sizes, kg							
liquid	39.3	40.8	39.1	39.3	NS	NS	NS
DM	4.6	5.1	4.7	4.7	NS	NS	NS
NDF	3.1	3.4	3.3	3.0	NS	NS	0.01
indigestible NDF	2.6	2.8	2.8	2.5	NS	NS	0.04
Starch	0.36	0.55	0.36	0.39	0.03	<0.01	0.04

¹ Treatment: DF = dry fine, DC = dry coarse, MF = high moisture fine, MC = high moisture coarse.

² C = Main effect of conservation method; G = Main effect of fineness of grinding; C x G = Interaction of C and G.

³ INDF (influx) rate of passage = rate of passage of indigestible NDF calculated with indigestible NDF intake.

⁴ INDF (outflux) rate of passage = rate of passage of indigestible NDF calculated with duodenal indigestible NDF flow.

⁵ DNDF rate of passage = rate of passage of digestible NDF calculated with duodenal indigestible NDF flow.

⁶ DNDF rate of digestion = rate of digestion of digestible NDF.

Table 2-6 Effect of treatment on ruminal pH and volatile fatty acids

	Treatment ¹				P = ²		
	DF	DC	MF	MC	C	G	C x G
Daily mean pH	6.70	6.63	6.57	6.57	0.03	NS	NS
pH variance	0.03	0.02	0.04	0.06	0.06	NS	NS
pH range	1.06	0.66	1.01	1.33	NS	NS	NS
Hours, pH < 6.0	0.1	0.1	0.5	0.4	NS	NS	NS
Hours, pH < 5.5	0.0	0.0	0.0	0.13	NS	NS	NS
Area, pH < 6.0	1.50	.50	8.75	27.25	NS	NS	NS
Area, pH < 5.5	0.0	0.0	2.13	16.25	NS	NS	NS
Total VFA, mM	62.3	61.5	66.4	63.8	0.05	NS	NS
Acetate (A), mol/100 mol	59.5	58.6	58.3	60.3	NS	NS	0.09
Propionate (P), mol/100 mol	21.2	21.4	20.4	19.4	<0.01	NS	0.10
A:P	2.8	2.7	2.9	3.1	0.01	NS	0.08
Butyrate, mol/100 mol	12.8	13.0	13.8	13.4	NS	NS	NS
IsoButyrate, mol/100 mol	3.2	3.4	3.4	3.2	NS	NS	NS
Valerate, mol/100 mol	0.82	0.81	0.98	.89	NS	NS	NS
Isovalerate, mol/100 mol	2.6	2.8	3.1	2.9	NS	NS	NS
Formate, mol/100 mol	3.7	4.7	4.5	3.1	NS	NS	0.03
Lactate, mM	ND ³	ND	ND	ND			
Ruminal NH ₃ N (mg/dl)	9.3	10.6	10.3	11.7	NS	0.10	NS

¹Treatment: DF = dry fine, DC = dry coarse, MF = high moisture fine, MC = high moisture coarse.² C = Main effect of conservation method; G = Main effect of fineness of grinding; C x G = Interaction of C and G.³ ND = not detected

Table 2-7 Effect of treatment on intake, body weight and body condition score

	Treatment ¹				P = ²		
	DF	DC	MF	MC	C	G	C x G
DMI, kg/d	7.6	7.9	7.6	7.7	NS	NS	NS
DMI/BW, %	1.6	1.7	1.6	1.6	NS	NS	NS
BW, kg	510.8	508.9	513.9	514.8	NS	NS	NS
BW change, kg/21d	29.2	25.0	26.7	21.3	NS	NS	NS
BCS	3.66	3.66	3.66	3.69	NS	NS	NS
BCS change /21 d	0.2	0.09	0.06	0.0	NS	NS	NS

¹Treatment: DF = dry fine, DC = dry coarse, MF = high moisture fine, MC = high moisture coarse .

² C = Main effect of conservation method; G = Main effect of fineness of grinding; C x G = Interaction of C and G.

Table 2-8 Effect of treatment on feeding behavior.

	Treatment ¹				P = ²		
	DF	DC	MF	MC	C	G	C x G
Eating:							
Meals, #/d	11.3	10.9	10.0	10.2	0.02	NS	NS
Meal size, kg	0.75	0.78	0.77	0.80	NS	NS	NS
Meal length, min	18.1	22.0	21.5	19.4	NS	NS	NS
Eating time, min/d	197	233	209	186	NS	NS	NS
Interval, min	102	103	104	104	NS	NS	NS
Chews, /meal	800	998	921	775	NS	NS	0.05
Chews, /d	8714	10408	8724	7262	0.09	NS	0.08
Chews, /min	49.6	52.7	49.0	46.9	0.07	NS	NS
Rate, g/min	45.9	34.4	36.2	42.1	NS	NS	0.07
Ruminating:							
Bouts, #/d	13.2	13.8	16.5	14.2	NS	NS	NS
Bout length, min	25.2	27.7	27.0	27.6	NS	NS	NS
Ruminating min /d	911	917	869	869	NS	NS	NS
Interval, min	89.6	78.8	58.5	75.2	NS	NS	NS
Chews, /bout	1212	1526	1476	1441	NS	NS	NS
Chews, /d	17477	22078	24922	21626	NS	NS	NS
Chews, /min	47.5	27.0	26.2	26.9	NS	NS	NS
Total chewing, min/d	1108	1150	1078	1055	NS	NS	NS
Total chews, /d	26191	32486	33646	28888	NS	NS	NS
Water intake, l/d	21.7	20.5	22.0	21.0	NS	NS	NS

¹Treatment: DF = dry fine, DC = dry coarse, MF = high moisture fine, MC = high moisture coarse.² C = Main effect of conservation method; G = Main effect of fineness of grinding; C x G = Interaction of C and G.

Table 2-9 Effect of treatment on N intakes and N metabolism of gastrointestinal tract of pregnant heifers

	Treatment ¹				P = ²	
	DF	DC	MF	MC	C	G
N intake, g/d	193.8	198.8	188.8	193.8	NS	NS
Passage to duodenum						
Total N						
g/d	139.5	146.8	124.7	128.6	<0.01	NS
% of N Intake	75.8	77.8	70.3	68.9	<0.01	NS
NAN ³						
g/d	136.2	142.6	121.5	125.4	<0.01	NS
Digestibility, % of N Intake	74.5	75.3	68.5	67.2	0.03	NS
NANMN ⁴						
g/d	34.4	38.5	13.5	35.7	0.03	0.02
% of NAN	26.2	26.3	11.0	28.4	0.03	0.02
% of N Intake	18.9	19.4	7.5	19.6	0.05	0.01
Microbial N						
g/d	101.8	104.1	107.9	89.7	NS	NS
% of NAN	73.8	73.7	89.0	71.6	0.05	0.01
g/kg of OMAD ⁵	42.0	46.2	35.2	34.5	0.06	NS
g/kg of OMTD ⁶	23.7	26.4	21.4	21.7	0.08	NS
N digested postruminally,						
g/d	95.1	104.2	84.2	88.2	<0.01	NS
digestibility, % of N Intake	49.1	52.4	44.6	45.5	0.05	NS
% of N passage to duodenum	68.2	71.0	67.5	68.6	NS	NS
Total tract disappearance						
g/d	148.9	156.0	147.6	153.7	NS	NS
apparent digestibility, % of N Intake	76.8	78.5	78.2	79.3	NS	0.10

¹Treatment: DF = dry fine, DC = dry coarse, MF = high moisture fine, MC = high moisture coarse.²C = Main effect of conservation method; G = Main effect of fineness of grinding; C x G = Interaction of C and G.³NAN = nonammonia nitrogen; ⁴NANMN = Nonammonia nonmicrobial nitrogen, ⁵OMAD = Organic matter apparently digested in the rumen; ⁶OMTD = Organic matter truly digested in the rumen

CHAPTER 3

EFFECTS OF FINENESS OF GRINDING AND CONSERVATION METHOD OF CORN GRAIN ON RUMINAL AND WHOLE TRACT DIGESTIBILITY, RUMINAL MICROBIAL PROTEIN PRODUCTION, FEEDING BEHAVIOR, AND MILK YIELD OF PRIMIPAROUS HOLSTEIN COWS AFTER CALVING

ABSTRACT

The effects of fineness of grinding and conservation method of corn grain on ruminal and whole tract digestibility, ruminal microbial protein production, feeding behavior and milk yield of primiparous Holstein cows were examined. Eight ruminally and duodenally fistulated Holstein cows (39 ± 11 DIM) were utilized in a duplicated 4×4 Latin square design balanced for carryover effects with 21-d periods. Corn treatments were dry corn, ground finely or coarsely and high moisture corn, ground finely or coarsely prior to feeding. Diets contained 49% alfalfa silage and 38% corn grain. High moisture conservation and fine grinding increased rate of starch digestion in the rumen which resulted in increased ruminal and whole tract digestibility. However, only high moisture corn decreased mean ruminal pH and increased variance in ruminal pH. High moisture conservation decreased ruminal digestibility of NDF and ADF but increased NDF and ADF digestion postruminally resulting in reduced whole tract digestibility for ADF only. High moisture conservation decreased the daily number of meals consumed and tended to increase meal size with no effect of treatment on DMI. Fine grinding decreased rumen pool sizes of liquid, DM, NDF, indigestible NDF and starch. High moisture conservation and fine grinding had greater gain (or less loss) of BW per day, but had no effect on BCS. Fine grinding decreased microbial N efficiency and microbial N yield was not affected by treatment. Fine grinding seems more beneficial to maximize FCM production than high moisture conservation for early lactation dairy cows.

3.1 INTRODUCTION

Corn is the most important source of starch for dairy cows in the eastern and midwestern US. Starch utilization by dairy cattle varies widely by processing and physiological status of animals (Nocek and Tamminga, 1991). These differences might be due to effects of processing, corn genetics, maturity at harvest and conservation method, animal factors such as level of intake, body size, pregnancy and many other factors. Corn grain is harvested at high moisture content (25-35% moisture) and ensiled or field dried to approximately 15% moisture. Physical processing of whole grain such as grinding and rolling increased total tract starch digestibility (Theurer et al., 1986). Site of starch digestion, which is also affected by conservation method and processing (Nocek and Tamminga, 1991), can affect animal performance such as altering energy available for microbial growth, forms of energy absorbed, efficiency of DE utilization, ruminal fermentation and production, meal patterns and DM intake. Level of intake affects residence time in the rumen and might affect site of starch digestion. Stanley et al. (1993) reported that indigestible ADF passage increased across the prepartum period (before calving 61 days to before calving 6 days) and peaked just before calving. Postpartum indigestible ADF passage was slower than 6 days before calving but still greater than 61 days before calving. Colucci et al. (1982) also found that retention time of digesta was shorter in the gastrointestinal tract with increasing intake for Holstein dairy cows. Nocek and Tamminga (1991) reported that maximum milk production was associated with maximum intake of both ruminally and intestinally digested starch.

Although there is research in the literature which compares site of starch digestion across grain sources such as barley, corn and sorghum (Oliveira, 1993; Grings, 1992; Knowlton et al., 1996b; Yang, 1997) and processing such as grinding and steam-flaking (Knowlton et al., 1996a; Plascencia, 1997), there is no published research on the effects of processing high moisture corn and dry corn from the same source for early lactation dairy cattle. The objective of this experiment was to evaluate the effects of processing (fine or coarse) and conservation method (high moisture ensiled or field dry) of corn on performance, ruminal and whole tract digestibility, ruminal microbial protein production and feeding behavior of early lactation Holstein cows.

3.2 MATERIALS AND METHODS

3.2.1 Corn Grain and Alfalfa Silage Harvest and Preservation

The same corn grain and alfalfa silage were used for this experiment as were used in the experiment described in Chapter 2. High moisture corn grain was harvested at 67.2% DM from one half of a 7-acre loamy sand field in Michigan State University campus on October 5, 1994. Dry corn was harvested from the remaining 7-acre field at 83% DM on December 13, 1994 and artificially dried to 86% DM. High moisture corn was ensiled in a silage bag (UpNorth Plastics Inc., Cottage Grove, MN) and ground finely or coarsely prior to feeding. Corn population in the field was 28,000 plants per acre. Dry corn was mixed and divided in half. Half of the dry corn was finely ground, and half was coarsely ground and was stored in sealed bags in a trailer. First -cutting

alfalfa was ensiled in a 2.5-m diameter silage bags (50 tons; Ag Bagger®, Ag Bag Corp., Blair, NE) to minimize variation and reduce spoilage at feed out.

3.2.1 Experimental Design and Data Collection

The same cows were used for this experiment as were used in the experiment described in Chapter 2. Eight ruminally and duodenally cannulated early lactation Holstein primiparous cows (29 months old, 39 ± 11 DIM; $X \pm SD$) were utilized in a duplicated 4×4 Latin square design. Cows were assigned to square by expected calving date and squares were balanced for carryover effects so that each treatment followed the other treatment an equal number of times. Within a square, each cow was assigned randomly to one of four treatment combinations. Cows were arranged in the same order as before calving. A 2×2 factorial arrangement of treatments was used in each square. Dietary treatments were corn particle size (fine or coarse) and corn conservation method (high moisture or field dried). Experimental treatment periods were 21-d, including 10 days for diet adjustment followed by 11 days of data collection. The animal care protocol was approved by All-University Committee on Animal Use and Care of Michigan State University. The approved animal use form number was 06/95-088-00. Eight cows were ruminally and duodenally cannulated at 21 months old. Duodenal cannula surgery was as described in Chapter 2.

Diets consisted of alfalfa silage, dry or high moisture corn, soybean meal, minerals and vitamins for each treatment period (Table 3-1 and 3-2; values represent mean ingredient and nutrient composition throughout the experiment). The diets were balanced to 27% NDF, 41% starch and 16.5% crude protein. Minerals and vitamins were supplemented to meet requirements (NRC, 1989). High moisture corn was ground prior to feeding through a mill without (coarse) or with (fine) a 1 cm screen (Mighty Mac

Chipper Shedder, Mackissic Inc., Parker Ford, PA). Five alfalfa silage samples from different sites of the silage bag were analyzed for DM, NDF and crude protein, and the average values were used for diet formulation for the experiment.

Alfalfa silage, corn treatments, soybean meal and mineral-vitamin mix were weighed in individual polyethylene mangers for each cow and mixed by hand. Cows were fed once daily at 1200 h at 110% of expected intake. Ration offered was recorded for each cow daily, and weights of orts were recorded prior to each feeding. Dry matter intake was calculated as the average daily DMI from d 12 to d 21 of each period. Dietary ingredients (0.5 kg) and individual cow orts (12.5% of orts as wet weight basis) were collected daily during the collection period, frozen and composited within each collection period. Alfalfa silage was analyzed weekly for DM content during the experiment and diets were re-balanced accordingly.

Cows were milked twice daily in their stalls at 0600 and 1700 h. Milk weight was recorded for each cow every milking. Milk samples were taken at each milking on d 11, 12, 13, and 14 of each period and analyzed for fat, protein, lactose, and SCC with infrared spectroscopy by Michigan DHIA (East Lansing). Fat corrected milk was calculated assuming 0.7% ash (NRC, 1989).

Cows were housed in tie stalls bedded with chopped newspaper and were exposed to continuous light throughout the experiment. Cows were allowed to exercise for approximately 30 min in a dry lot following milking except during collection of behavioral data. Rumen empty body weights were measured on the last 2 days of the each period and on 2 days preceding the first period. Body condition score was evaluated to the quarter point on a five-point scale (1 = thin to 5 = fat) on d 20 of each period and 2 days prior to beginning the first period.

Duodenal flow was estimated using a double marker system (Faichney, 1980) with Cr-mordanted wheat straw NDF as a particulate phase marker and Co-EDTA as a liquid phase marker. Chromium-mordanted NDF and Co-EDTA were prepared as

described by Udén et al. (1980). Chromium mordanted wheat straw was ground through a Wiley mill (2 mm screen; Arthur H. Thomas, Philadelphia, PA) and was provided at approximately 0.07% of DM intake (30 g/d/cow). Chromium content of the fiber was approximately 5% of DM resulting in a Cr intake of 1.6 g/d/cow. Gelatin capsules (1.5 Oz, Tropac Inc., Airfield, NJ) filled with chromium mordanted wheat straw were dosed into the rumen 2 times/d from d 10 until d 18 at 0730 and 1930 h. Co-EDTA was dosed at approximately 0.04% of DM intake (0.43 g Co/d, 0.91 Co/ l solution) by semi-continuous infusion into the rumen by a peristaltic pump (FPU101, Omegaflex™ peristaltic pump, Omega Engineering Inc., Stamford, CT). Pumps had a flow rate of 3.3 ml/min but were turned on intermittently for 1 minute out of every 10 minutes to achieve an average flow rate of 0.33 ml/min over the 9 days (475 ml Co-EDTA solution/d, 0.43 g Co/d). A priming dose of each marker was given on d 9 of the 21-d period at 3 times the daily dose.

For determination of ruminal and total tract nutrient digestibility, duodenal digesta and feces were sampled every three hours beginning at 1200 h on d 15 and continuing until 1100 h on d 18. The sampling time was adjusted ahead 1 h daily so that 24 samples representing each hour in a day would be collected. Two separate samples of duodenal digesta were collected (400 ml and 75 ml). The 400 ml samples were frozen immediately at -20°C until analysis and the 75 ml samples were preserved with 5 ml of 6 N HCl and frozen for later analysis of NH_3 . Fecal samples (400 g) were collected and frozen immediately at -20°C until analysis.

Samples of ruminal fluid were collected every 3 h of a 24-h period starting at 1200 h on d 19 to account for diurnal effects on concentration of metabolites. Samples of rumen fluid from five sites in the rumen were mixed and filtered through 4 layers of cheesecloth to remove particulate matter. Three 75 ml subsamples of ruminal fluid were taken from this sample for each time period. One was preserved with 5 ml of 6 N HCl for NH_3 analysis, one was preserved with 5 ml of 20% NaOH for VFA and lactate

analysis and one was taken for purine analysis. All subsamples were frozen (at -20°C) immediately following collection.

Ruminal digesta was evacuated manually from each cow at 0630 h on d 20 (5.5 h prefeeding) and 1730 h on d 21 of the experiment period (5.5 h postfeeding). A 10% aliquot of digesta was separated during evacuation for ease of subsampling and measuring liquid and solid phases. This aliquot was weighed, mixed by hand and strained through four layers of cheesecloth to separate it into solid and liquid phases. Solid phase samples were weighed and subsampled a 400 g solid sample was frozen for determination of DM and nutrient composition. Three separate subsamples (400 ml, 75 ml, and 75 ml) of rumen liquid were collected. The 400 ml samples were frozen (-20°C) immediately for DM, NDF, ADF, acid detergent sulfuric acid-lignin, starch and indigestible NDF analysis, while the 75 ml subsample of ruminal fluid was preserved with 5 ml of 6 N HCl and frozen (-20°C) for later NH_3 analysis, and 75 ml subsample of ruminal fluid was preserved with 5 ml of 20% NaOH, and frozen (-20°C) for later VFA and lactate analysis. Rumen total digesta weight and volume were measured at each evacuation.

Feed disappearance, chewing behavior and ruminal pH were measured continuously for 4 days from d 11 to d 14 of each experiment period using a computerized data acquisition system described by Dado and Allen (1993). Data were written to files every 5 seconds for each variable, for each cow. Chewing monitors were fitted to cows 1 d prior to collection to allow for cow adaptation, and remained in place for the throughout the behavior collection period. No other cows were present in the barn during the study. Load cells for determination of feed consumption were calibrated prior to each collection period. Electrodes for pH determination (described by Knowlton et al., 1996a) were calibrated daily immediately before feeding. Electrodes generally held their calibration within 0.05 pH units. Electrodes outside this range were recalibrated or replaced. Occasional problems with jaw movement detectors, load cells, and pH

electrodes were recorded, and feeding behavior data from that cow for the entire day was removed from the data file prior to analysis. Water intake was recorded daily from water meters at each stall (Omega MKH 4465 5/8, Omega Engineering Inc., Stamford, CT).

3.2.3 Analysis of Samples

Samples of each corn treatment were taken daily from d 12 until d 21 of each period for particle size analysis. A representative sample of each corn treatment was dry sieved through 8 sieves (Sieve apertures: 4750, 2360, 1180, 600, 300, 150, 75 μm and bottom pan), using a sieve shaker (Model RX-86, W.S. Tyler Inc., Gastonia, NC) for approximately 15 min until the bottom pan weight was constant (ASAE, 1968). Mean particle size of corn was calculated and variance was determined by fitting the data to a gamma distribution (Allen et al., 1983).

Diet ingredient andorts samples were analyzed for DM, ash, NDF, ADF, acid detergent sulfuric acid-lignin, starch, CP and indigestible NDF. The samples were dried in a forced air oven at 55°C for 72 hours and analyzed for DM content. All samples were ground with a Wiley mill (1-mm screen Arthur H. Thomas, Philadelphia, PA). Ash was determined following sample ignition at 500°C for 5 hours. Samples were analyzed sequentially for NDF (procedure A, Van Soest et al., 1991), ADF (AOAC, 1984) and acid detergent sulfuric acid-lignin (Goering and Van Soest, 1970). Crude protein was analyzed according to Hach et al. (1987). Indigestible NDF was estimated as NDF content of sample following in vitro fermentation in buffered rumen media for 120 hours (Goering and Van Soest, 1970). Starch was analyzed by a one-stage enzymatic method of glucoamylase (Diazyme L-200, Miles, Inc., Elkhart, IN) with a NaOH gelatinization step (O'Neil et al., 1993). Following gelatinization the sample was centrifuged at 26,000 $\times g$ for 20 min, and concentration of glucose in the supernatant was analyzed by HPLC

using an Aminex fast carbohydrate column (100×7.8 mm, catalog number 125-0105; Bio-Rad Laboratories, Richmond, CA). Column temperature was 85°C , and the solvent was degassed deionized distilled H_2O with a flow rate of 0.6 ml/min. Detection was by refractive index (Waters 410, Millipore Corp., Milford, MA). Concentration of all nutrients except DM was expressed as a percentage of the DM determined from forced air oven drying at 105°C .

Daily frozen duodenal samples ($n = 8$) were chopped and subsampled on an equivalent wet weight basis, lyophilized and ground with a mortar and pestle. Duodenal digesta were analyzed for DM, NDF, ADF, acid detergent sulfuric acid-lignin, ash, CP, starch and indigestible NDF as described previously. Ruminal samples for purine analysis were measured as described later. Fecal samples were thawed, subsampled and composited on an equivalent wet weight basis for each cow per day and dried in a forced air oven at 55°C for 72 hours and analyzed for DM content. Fecal samples were ground with a Wiley mill (1 mm screen) and analyzed for DM, NDF, ADF, acid detergent sulfuric acid-lignin, ash, CP, starch and indigestible NDF as described previously.

For analysis of flow markers, daily frozen duodenal samples were chopped into snow using a food processor (84142 Food cutter, Hobart Manufacturing Co., Troy, OH), subsampled on an equal wet weight, thawed, and partitioned into liquid and solid phases by centrifuge (RC5C, Sorvall Instrument, E. I. du Pont de Nemours & Co., Inc., Hoffman Estates, IL) at $500 \times g$ for 10 min at 4°C . Each phase of sample was dried in a 100°C forced air oven for later chromium and cobalt analysis. Chromium and cobalt concentration of feeds, duodenal liquid phase, duodenal solid phase and feces were determined by atomic absorption spectrometry according to the manufacturers' recommendations (Smith-Hieftje 4000, Thermo Jarrell Ash Co., Franklin, MA) following digestion using phosphoric acid-manganese sulfate solution (Williams et al., 1962). Duodenal digesta flow was calculated as described by Armentano and Russell (1985).

Ruminal samples for purine analysis were prepared following the procedure of Overton et al. (1995). Purines were measured (Zinn and Owens, 1986), modified by Overton et al. (1995), as a bacterial marker. Microbial protein production was calculated by dividing purine and nitrogen ratio of rumen microbes by purine percentage of duodenal DM per day (Zinn and Owens, 1986).

Duodenal and ruminal samples for NH_3 analysis were thawed and composited on an equivalent volume basis for each cow per day. Ammonia was measured using the general procedure of McCullough (1967), modified by Broderick and Kang (1980). Absorbance was determined using a spectrophotometer (1 cm length path, DU-64 Spectrophotometer, Beckman Instruments, Inc., Fullerton, CA).

Ruminal fluid samples were thawed and composited on an equivalent volume basis for each cow per day for VFA and lactate analysis. Composite ruminal fluid samples were centrifuged at $26,000 \times g$ for 30 min. Concentrations of VFA and lactate of supernatant were determined by HPLC as described by Dado and Allen (1995).

Ruminal solid and liquid subsamples from the evacuated rumen digesta were dried in a 100°C forced air oven, and analyzed for DM, NDF, ADF, acid detergent sulfuric acid-lignin, ash, starch, and indigestible NDF as described previously. Rumen liquid subsamples were analyzed for NH_3 and VFA as described previously. Rumen pool sizes (kg) of DM, liquid, NDF, starch and indigestible NDF were calculated by multiplying the concentrations of each by the rumen digesta weight (kg).

Ruminal starch and NDF turnover time were determined by dividing the pool size of starch or NDF by hourly starch or NDF intake. Rates of starch, indigestible NDF (INDF) and potentially digestible NDF (DNDF) passage from the rumen were determined by dividing starch or INDF or DNDF daily out flow to duodenum (OUTFLUX, dual markers system) by the pool size of starch, or indigestible NDF or digestible NDF. Rate of digestion of starch or DNDF was calculated by the reciprocal of the turnover time (equal to rate of digestion and rate of passage) minus rate of passage of

starch or DNDF. Rate of INDF passage from the rumen (INFLUX, internal marker system) was determined by the method of Dado and Allen (1995) by dividing the rumen pool size of INDF into hourly intake of INDF. Estimated rate of water passage from the rumen was calculated as duodenal flux of water divided by the pool size of water in the rumen. This calculation assumes no net water absorption prior to the duodenum and that Co-EDTA passes at the same rate as water.

Mean ruminal pH, hours below pH 5.5 and 6.0, and the areas of the pH $\times$ time curve under pH 5.5 and 6.0 (Mackie and Gilchrist, 1979) were calculated. The area of the pH $\times$ time curve below a critical pH gives a weighted average of the deviation from this pH which is more meaningful to optimal ruminal pH (Allen and Beede, 1996).

For feeding behavior data analysis, means were calculated for number of meals per day, meal size (kg per meal), minutes between meals, eating time in minutes per meal and per day, eating chews per meal and per day, eating chew rate (chews per minute), number of ruminating bouts per day, minutes between ruminating bouts, ruminating time in minutes per bout and per day, ruminating chews per bout and per day, ruminating chew rate and total chewing per day (eating chews and ruminating chews) using a program written in SAS programming language (Version 6.1, SAS Institute Inc., Cary, NC).

3.2.4 Statistical Analysis

Data were analyzed using the fit model procedure of JMP (Version 3.2, SAS Institute Inc., Cary, NC) as duplicated ($n = 2$) 4×4 Latin squares using the following model:

$$Y_{ijkl} = \mu + S_i + C_{j(i)} + P_k + T_l + ST_{il} + SP_{ik} + E_{ijkl}$$

where

μ = overall mean,

S_i = random effect of square ($i = 1$ to 2),

$C_{j(i)}$ = random effect of cow within square ($j = 1$ to 4),

P_k = random effect of period ($k = 1$ to 4),

T_l = fixed effect of treatment ($l = 1$ to 4),

ST_{il} = interaction of square and treatment,

SP_{ik} = interaction of square and period, and

E_{ijkl} = residual, assumed to be normally distributed.

A reduced model without square $\times$ treatment or square $\times$ period interactions was used when these effects were not significant ($P > 0.10$). Preplanned orthogonal contrasts were used to determine significance of the main treatment effects of conservation method, fineness of grinding and their interaction. Main effects and interactions were declared significant at $P < 0.05$, and $P < 0.10$, respectively.

3.3 RESULTS AND DISCUSSION

3.3.1 Composition of Diets and Particle Size

Chemical composition of the corn treatments appears in Table 3-1. Except for the expected effect of conservation method on DM content, only slight differences in composition were detected among treatments. Dry corn had an average of 1.5 units more NDF and an average of 0.14 units more lignin than high moisture corn. Indigestible NDF was higher for dry corn but the difference was greater for coarse corn than for finely ground corn. Starch content in the corn was higher for finely ground compared to coarsely ground for high moisture corn, but it was lower for finely ground in relation to coarsely ground for dry corn.

Diets contained 49% alfalfa silage, 38% corn grain and 9.7% soybean meal (Table 3-2). Dry matter of dry corn and high moisture diets were 52.1% and 48.2%. Diets containing high moisture corn had lower NDF, ADF and acid detergent sulfuric acid-lignin content compared to dry corn diets. Indigestible NDF was also lower for high moisture corn diet but the differences greater for coarsely ground than for finely ground corn diets. Starch content of high moisture corn diet was higher for finely ground corn diet related to coarsely ground corn diet, but starch content of dry corn diet was lower for coarsely ground corn diet compared to finely ground corn diet. These differences in chemical composition, although significant, were slight.

Mean particle size of dry fine corn, dry coarse corn, high moisture fine corn and high moisture coarse corn was $850 \pm 124 \mu\text{m}$, $4360 \pm 250 \mu\text{m}$, $2058 \pm 293 \mu\text{m}$, and $5739 \pm 286 \mu\text{m}$, respectively. Field dried conservation and fine grinding decreased particle size of corn grain ($P < 0.01$, Table 3-1). Because moisture contents for field dried

conservation and high moisture conservation were different, they were processed with different mills. There were similar reductions in particle size by fine grinding dry corn and high moisture corn (Figure 3-1).

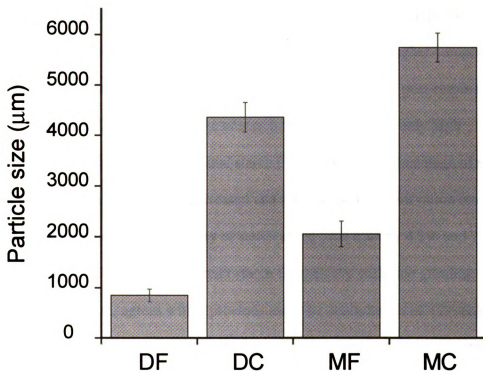


Figure 3-1 Particle size mean and standard deviation for four corn grains

DF: dry fine, MF: high moisture fine, DC: dry coarse, MC: high moisture coarse.

3.3.2 Nutrient Digestibility

Apparent ruminal starch digestibility was higher for fine grinding and for high moisture conservation (Table 3-3). Grinding corn finely increased ruminal starch digestibility an average of 65% compared to coarsely ground corn diets. High moisture conservation increased ruminal starch digestibility an average of 24% higher compared to dry corn diets. High moisture conservation and fine grinding decreased post-ruminal apparent starch digestibility as a percentage of starch intake. However, only high moisture conservation increased post-ruminal starch digestibility as a percentage of starch entering the duodenum. Fine grinding increased and high moisture conservation tended ($P = 0.07$) to increase apparent digestibility of starch in the total tract by 4.2% and 1.2% higher, respectively. The increased total tract starch digestibility with fine grinding and high moisture conservation, agrees with a previous study by Knowlton et al. (1996b). In the experiment conducted before calving (results reported in Chapter 2), high moisture conservation had no effect on starch apparently digested in the total gastrointestinal tract. In this experiment, the ratio of starch apparently digested in the rumen to that digested post ruminally was over 3-fold higher for the finely ground corn compared to coarsely ground corn. The significant interaction was due to the greater difference between fine and coarse grinding for the high moisture corn diets compared with the dry corn diets (Table 3-3).

High moisture conservation resulted in lower NDF and ADF intake for finely ground corn but not for coarsely ground corn (Table 3-4). High moisture conservation

also decreased the amount of NDF and ADF digested in the rumen and the ruminal digestibility of NDF and ADF but the reduction was greater for finely ground corn. Post-ruminal digestion of NDF was higher for high moisture corn than dry corn as amount per day, digestibility as a percentage of NDF intake, or as a percentage of NDF entering the duodenum, but the difference was greater for the finely ground treatment. The increased postruminal digestion of NDF for the high moisture corn diet compensated for the decreased ruminal NDF digestibility, resulting in no effect of treatment on total tract NDF digestibility. Fine grinding resulted in a greater amount of ADF digested post-ruminally, and both high moisture conservation and fine grinding increased postruminal ADF digestibility as a percentage of ADF intake but not as a percentage of ADF entering the duodenum. There was a trend towards reduced total tract ADF digestibility for high moisture conservation and for fine grinding. The reduction in ruminal NDF and ADF digestibility for the high moisture treatments compared to a reduction in ruminal pH for these treatments (Table 3-6). Increased digestibility of starch has been reported to decrease NDF digestion by decreasing rate of digestion and increasing lag time (Grant and Mertens, 1992).

High moisture conservation and fine grinding increased the apparent total tract digestibility of DM ($P < 0.05$, Table 3-3), by 0.9 units and 1.3 units, respectively. The apparent total tract digestibility of OM was higher for the high moisture and finely ground corn treatments averaging 1.3% and 1.7%, respectively (Table 3-3). Apparent OM digestibility in the rumen increased an average of 27.8% higher for finely ground corn compared to coarsely ground corn and an average of 9.2% higher for high moisture corn treatment compared with to dry corn diet. The proportion of OM truly digested in

the rumen also increased with high moisture conservation or fine grinding an average of 5.8% or 16.9% higher, respectively, compared to dry corn diet or coarsely ground corn diet. High moisture conservation and fine grinding increased whole tract OM digestibility, which differed from the experiment conducted before calving in which there was no effect of treatment on total tract OM digestibility. The amount of OM passage to the duodenum, expressed as a percentage of OM intake decreased as high moisture corn compared to dry corn and finely ground corn compared to coarsely ground corn. Postruminal OM digestibility decreased an average of 40% lower by finely ground corn compared to coarsely ground corn. However, postruminal OM digestibility was not affected by high moisture conservation, which differed from the experiment conducted before calving in which there was decreased postruminal OM digestibility by high moisture conservation.

3.3.3 Rumen Pool Size, Passage of Indigestible NDF and Starch, Ruminal pH and Volatile Fatty Acids

Fine grinding decreased rumen digesta volume and weight and decreased rumen pool sizes of liquid, DM, NDF and indigestible NDF (Table 3-5), which differed from the experiment conducted before calving. There was no effect of fine grinding on rumen digesta volume and weight or rumen pool sizes of liquid, DM, NDF and indigestible NDF for before calving. However, significant interactions of treatment were observed for rumen pool sizes of NDF and indigestible NDF, with larger rumen pool sizes of NDF

and indigestible NDF for coarse dry corn compared to fine dry corn, smaller rumen pool sizes of NDF and indigestible NDF for coarse high moisture corn compared with fine high moisture corn for the experiment conducted before calving. Conservation method had no effect on rumen digesta volume and weight or rumen pool sizes of liquid, DM, NDF, and indigestible NDF. There was no effect of treatment on density of digesta in the rumen. High moisture conservation and fine grinding increased rate of starch digestion in the rumen by an average of 63.8% and 138.4% higher, respectively, resulting in decreased ruminal turnover time and rumen pool size for starch for both treatments. The higher rate of digestion might be due to increased surface area available for enzymatic attack for the finely ground corn and increased solubility of endosperm protein increasing access of microbes to starch granules for the high moisture corn (Oke, et al., 1991). Finely ground corn increased rate of passage of INDF from the rumen calculated with both the INFLUX and OUTFLUX methods. In addition, fine grinding increased rate of digestion of potentially digestible NDF, with a greater increase for dry corn compared to high moisture corn. The increased rate of NDF digestion and passage resulted in decreased turnover time of NDF in the rumen for the fine corn treatments with a greater decrease for the dry corn than high moisture corn treatment and a decrease in NDF pool size for the finely ground treatments. There was no effect of treatments on water passage calculated with this method.

High moisture conservation decreased daily mean pH, increased pH variance and increased hours below pH 6.0 or 5.5 and area below pH 6.0 or 5.5 (Table 3-6). Fine grinding had no effect on ruminal pH but increased pH variance compared to coarsely ground corn. The assumed increase in fermentation acid production from greater ruminal

OM digestibility for the finely ground corn diets apparently was buffered adequately in the rumen to prevent a decrease in ruminal pH. This is similar to the effect by high moisture conservation observed in the experiment conducted before calving (Table 2-6). Fine grinding decreased the concentration of ammonia N in the rumen an average of 12.4% lower compared with coarsely ground corn.

High moisture conservation tended to decrease acetate as a percentage of VFA averaging 3.6% compared to dry corn ($P = 0.11$, Table 3-6). High moisture conservation increased valerate as a percentage of VFA and decreased isovalerate as a percentage of VFA. Although there was no effect of treatment on total VFA, the numerical differences were similar to the effects of treatment on ruminal digestibility of OM and starch, with a greater value for fine corn replaced coarse corn and a higher for high moisture coarse corn compared to dry coarse corn treatment. Fine grinding decreased isovalerate as a percentage of VFA by an average of 10.8% lower. High moisture conservation and fine grinding had no effect on lactate concentration in the rumen.

3.3.4 Intake and Feeding Behavior Data

High moisture conservation and fine grinding resulted in greater gain (or less loss) of BW per day (Table 3-7), but only fine grinding increased body weight of early lactation dairy cows. Conservation method and fine grinding had no effect on daily DMI or DMI as a percentage of BW, which agrees with the experiment conducted before calving and the study by Knowlton et al (1996a). DMI as a percentage of BW averaged

3.35% for early lactation dairy cows. Although no effect of treatment was observed for DMI, high moisture treatment resulted in fewer meals per day ($P = 0.01$, Table 3-8). The animals consumed approximately 10.2 and 11.2 meals per day for high moisture corn and dry corn, respectively. High moisture corn tended to increase meal size ($P = 0.08$) but did not affect DMI. Eating rate was faster for the high moisture treatment averaging 21% than the dry corn diets. Eating time per day was shorter for high moisture corn than dry corn, which might have increased ruminal pH variance. A treatment interaction was observed for the number of chews per meal with greater number of chews per meal for high moisture fine corn in relation to dry fine corn but fewer number of chews per meal for high moisture coarse corn compared to dry coarse corn. Fine grinding tended to increase the number of chews per day ($P = 0.10$) compared to coarse corn, but the difference was greater for dry corn. There was no effect of treatment on rumination activity or total chewing activity. Water intake increased 7.7% for finely ground corn and 4.3% for dry corn treatment (Table 3-8), which agrees with a previous study (Knowlton et al., 1996a). Conservation method might have a greater effect on feeding behavior and ruminal pH than processing for corn grain.

3.3.5 Milk Production and Composition

Finely ground corn increased 4% fat correct milk (FCM) yield per day 1.4 kg compared to coarse corn ($P = 0.04$, Table 3-7), and dry corn tended to increase 4% FCM ($P = 0.10$, Table 3-7). Fine grinding increased milk protein 0.07 units compared to

coarse corn. Solids not fat as a percentage or as daily yield increased for the finely ground corn diets. Fine grinding and conservation method had no effect on percentage and yield of milk fat and milk lactose.

3.3.6 Microbial N Production and N Flow to the Duodenum

A significant interaction of treatment was detected for N intake which was higher for dry fine corn compared with dry coarse corn, and lower N intake for high moisture fine corn compared to high moisture coarse corn (Table 3-9).

Efficiency of microbial protein production per kg of OM apparently or truly fermented was lower for finely ground corn than coarsely ground corn averaging 22% or 19% lower, respectively. High moisture treatment tended to decrease efficiency of microbial protein production per kg of OM apparently fermented ($P = 0.10$, Table 3-9).

Compared to literature values for lactating cows N intake and N passage to the duodenum seem low (Clark et al., 1992). However, this might be because the cows used in this experiment were primiparous. High moisture conservation and fine grinding had no effect on the amount and proportion of total N, NAN, NAMN and microbial N passed to the duodenum. However, significant interactions of treatments were observed with greater total N and NAN passage to the duodenum as a percentage of N intake for dry coarse corn compared to dry fine corn, and lower total N and NAN passed to the duodenum as a percentage of N intake for high moisture coarse corn compared with high moisture fine corn.

Conservation method and fineness grinding had no effect on the amount of postruminal N flow per day, but high moisture conservation increased postruminal N digestibility as a percentage of N passage to the duodenum an averaging of 4.5% higher. Postruminal N digestibility as a percent of N intake increased with fine grinding for high moisture corn and decreased with fine grinding for corn. High moisture conservation increased post-ruminal digestibility of N as a percentage of N entering the duodenum which resulted in increased apparent total tract digestibility of N ($P < 0.01$). There was an interaction of treatment for the amount of total tract N disappearance per day with higher N digested in the total tract for dry fine corn compared with dry coarse corn, but lower N digested in the total tract for high moisture fine corn compared to high moisture coarse corn was detected ($P = 0.06$).

3.4 CONCLUSIONS

Fine grinding increased ruminal and total tract starch digestibility as well as OM digestibility to a greater extent than high moisture conservation and had no effect on ruminal pH. Fine grinding also resulted in a greater gain (or less loss) of BW per day, increased 4% fat-correct milk yield, and increased milk protein content. Although high moisture conservation decreased the daily number of meals consumed and tended to increase meal size, it had no effect on DMI. Fine grinding might be more beneficial to increase ruminal starch digestion for lactating cows than high moisture conservation.

TABLES

Table 3-1 Chemical composition and particle size of corn grain

	Corn grain treatments ¹				P = ²	
	DF	DC	MF	MC	C	G
Chemical composition						
55°C DM, %	87.1	87.4	65.6	65.5	<0.01	NS
OM, % of DM	98.1	98.2	98.1	98.1	NS	NS
CP, % of DM	9.4	8.9	8.9	9.5	NS	NS
NDF, % of DM	9.4	8.8	7.1	8.1	<0.01	NS
ADF, % of DM	2.6	2.6	2.3	2.5	NS	NS
Lignin, % of DM	0.82	0.82	0.66	0.70	0.02	NS
Indigestible NDF, % of DM	2.3	3.0	2.0	2.0	<0.01	<0.01
Starch, % of DM	76.0	76.9	77.5	76.2	NS	0.01
Particle size mean (μm)	850	4360	2058	5739	0.01	<0.01
						NS

¹ Corn grain treatments: DF = dry fine, DC = dry coarse, MF = high moisture fine, MC = high moisture coarse.

² C = Main effect of conservation method; G = Main effect of fineness of grinding; C x G = Interaction of C and G.

Table 3-2 Ingredient and chemical composition of diets.

	Treatment ¹				P =		
	DF	DC	MF	MC	C	G	C x G
Ingredients, % DM of diet							
Alfalfa silage ²	48.8	48.9	48.6	48.5			
Dry corn							
Fine	38.1	-	-	-			
Coarse	-	38.1	-	-			
High moisture corn							
Fine	-	-	38.5	-			
Coarse	-	-	-	38.5			
Soybean meal ³	9.7	9.7	9.6	9.6			
Mineral vitamin mix ⁴	3.4	3.4	3.4	3.4			
Chemical composition							
55°C DM, %	52.1	52.0	48.2	48.2	<0.01	NS	NS
OM, % of DM	92.5	92.6	92.6	92.6	NS	NS	NS
CP, % of DM	16.6	16.4	16.4	16.6	NS	NS	NS
NDF, % of DM	27.9	27.6	26.9	27.0	<0.01	NS	NS
ADF, % of DM	19.4	19.4	19.2	19.2	<0.01	NS	NS
Lignin, % of DM	5.3	5.3	5.3	5.3	<0.01	NS	NS
Indigestible NDF, % of DM	15.6	15.9	15.4	15.4	<0.01	0.03	<0.01
Starch, % of DM	40.5	40.8	41.3	40.5	NS	NS	0.05

¹ Treatments: DF = dry fine corn, DC = dry coarse corn, MF = high moisture fine corn, MC = high moisture coarse corn.

² Alfalfa silage composition: 36.3% DM at 55°C. Each of the following were measured as a percentage of DM:

45.2% NDF, 35.2% ADF, 8.4% lignin, 17.6% CP, and 16.2% starch.

³ Soybean meal composition: 89.3% DM at 55°C. Each of the following were measured as a percentage of DM:

20.1% NDF, 12.2% ADF, .77% lignin, 45.1% CP, and 20.7% starch.

⁴ Mineral vitamin mix composition: 88.4% DM at 55°C. Each of the following were measured as a percentage of DM:

7.5% NDF, 1.8% ADF, .49% lignin, 3.4% CP, and 45.3% starch.

Table 3-3 Effect of treatment on intakes and digestibilities of DM, OM, and starch

	Treatment				P =		
	DF	DC	MF	MC	C	G	C x G
DM							
Intake, kg/d	15.6	14.8	14.4	14.7	NS	NS	NS
ADTT, kg/d	12.8	12.0	12.0	12.0	0.03	0.01	NS
digestibility, % of Intake	81.5	80.2	82.3	81.3	0.03	0.01	NS
OM							
Intake, kg/d	14.4	13.7	13.3	13.6	NS	NS	NS
Apparently digested in the rumen							
kg/d	8.9	6.2	8.6	7.1	NS	< 0.01	0.04
digestibility, % of Intake	59.5	44.3	62.3	51.0	0.03	< 0.01	NS
Truly digested postruminally, kg/d							
kg/d	11.1	8.8	10.8	9.4	NS	< 0.01	NS
digestibility, % of Intake	76.5	64.3	79.7	69.3	0.07	< 0.01	NS
Passage to duodenum, kg/d	5.5	7.5	4.7	6.5	0.09	< 0.01	NS
Apparently digested postruminally, kg/d							
kg/d	3.0	4.9	2.5	4.1	NS	< 0.01	NS
digestibility, % of Intake	20.8	35.8	18.8	30.1	NS	< 0.01	NS
% of entering duodenum	54.5	65.3	53.2	63.1	NS	< 0.01	NS
ADTT							
kg/d	11.9	11.1	11.1	11.2	NS	NS	NS
digestibility, % of Intake	82.0	80.4	82.8	81.7	0.02	< 0.01	NS
Starch							
Intake, kg/d	6.2	6.1	5.9	5.9	NS	NS	NS
Apparently digested in the rumen							
kg/d	4.0	2.1	4.6	2.8	0.02	< 0.01	NS
digestibility, % of Intake	63.2	36.8	76.3	47.8	0.02	< 0.01	NS
Passage to duodenum, kg/d	2.2	3.9	1.2	3.1	0.05	< 0.01	NS
Apparently digested postruminally, kg/d							
kg/d	1.9	3.4	1.1	2.7	0.05	< 0.01	NS
digestibility, % of Intake	30.6	55.7	18.6	45.8	0.05	< 0.01	NS
% of entering duodenum	86.4	87.2	91.7	87.1	0.04	NS	NS
Ratio of % digested in the rumen to postrumen							
ADTT	2.1	0.62	3.65	1.00	< 0.01	< 0.01	0.04
kg/d							
digestibility, % of Intake	5.9	5.6	5.7	5.5	0.07	< 0.01	NS
	95.7	91.8	96.8	92.9	0.07	< 0.01	NS

Table 3-4 Effect of treatment on intakes and digestibilities of ADF and NDF

	Treatment ¹				P = ²		
	DF	DC	MF	MC	C	G	C x G
NDF							
Intake, kg/d	4.4	4.0	3.8	4.0	<0.01	NS	<0.01
Truly digested in the rumen							
kg/d	2.5	2.1	1.8	2.0	<0.01	NS	<0.01
digestibility, % of Intake	54.9	50.5	46.0	50.1	<0.01	NS	<0.01
Passage to duodenum							
kg/d	1.9	1.9	2.0	1.9	NS	NS	NS
Truly digested postruminally, kg/d	0.06	0.27	0.41	0.31	0.02	NS	0.06
digestibility, % of Intake	1.4	6.8	10.8	7.8	0.02	NS	0.06
% of entering duodenum	3.2	14.2	20.5	16.3	0.02	NS	0.03
TDIT ³							
kg/d	2.6	2.4	2.2	2.4	0.05	NS	0.07
digestibility, % of Intake	57.2	57.9	57.1	57.9	NS	NS	NS
ADF							
Intake, kg/d	3.1	2.9	2.8	2.9	<0.01	NS	0.04
Truly digested in the rumen							
kg/d	1.9	1.9	1.5	1.7	<0.01	NS	0.03
digestibility, % of Intake	59.2	61.1	51.8	59.4	<0.01	NS	<0.01
Passage to duodenum							
kg/d	1.2	1.1	1.3	1.1	NS	<0.01	NS
Truly digested postruminally, kg/d	0.14	0.10	0.28	0.12	NS	0.07	NS
digestibility, % of Intake	4.5	3.4	10.0	4.1	<0.01	0.07	NS
% of entering duodenum	11.7	9.1	21.5	10.9	NS	NS	NS
TDIT ³							
kg/d	2.0	1.9	1.8	1.9	NS	NS	NS
digestibility, % of Intake	64.5	65.5	62.2	64.4	0.06	0.07	NS

¹Treatment: DF = dry fine, DC = dry coarse, MF = high moisture fine, MC = high moisture coarse.

²C = Main effect of conservation method; G= Main effect of fineness of grinding; C x G = Interaction of C and G.

³TDIT = truly digested in the total tract.

Table 3-5 Effect of treatment on ruminal passage, digestion and pool sizes

	Treatment ¹				P= ²	
	DF	DC	MF	MC	C	G
Rumen parameters						
Water passage, %/h	7.8	7.5	8.1	7.6	NS	NS
Starch turnover time, h	3.0	4.6	2.5	3.9	0.05	<0.01
Starch rate of passage, %/h	12.7	14.6	9.3	11.1	NS	NS
Starch rate of digestion, %/h	22.8	7.6	33.7	16.1	0.01	<0.01
NDF turnover time, h	28.3	33.9	31.2	33.6	0.10	<0.01
INDF (influx) rate of passage ³ , %/h	2.5	2.2	2.4	2.2	NS	<0.01
INDF (outflux) rate of passage ⁴ , %/h	1.5	1.2	1.7	1.3	0.09	0.02
DNDF rate of passage ⁵ , %/h	2.2	2.7	2.0	2.5	NS	NS
DNDF rate of digestion ⁶ , %/h	7.2	4.1	4.5	4.4	0.03	<0.01
Digesta volume, l	75.6	82.5	74.4	80.8	NS	0.02
Digesta wt, kg	61.8	66.0	59.4	65.4	NS	<0.01
Digesta density (kg/l)	0.82	0.80	0.80	0.81	NS	NS
Rumen pool sizes, kg						
liquid	54.1	57.3	52.0	57.2	NS	<0.01
DM	7.7	8.6	7.3	8.3	NS	0.02
NDF	5.1	5.7	5.0	5.5	NS	0.02
indigestible NDF	4.3	4.6	3.0	4.5	NS	0.02
Starch	0.76	1.19	0.61	0.92	0.04	<0.01

¹Treatment: DF = dry fine, DC = dry coarse, MF = high moisture fine, MC = high moisture coarse.

² C = Main effect of conservation method; G = Main effect of fineness of grinding; C x G = Interaction of C and G.

³ INDF (influx) rate of passage = rate of passage of indigestible NDF calculated with indigestible NDF intake

⁴ INDF (outflux) rate of passage = rate of passage of indigestible NDF calculated with duodenal indigestible NDF flow

⁵ DNDF rate of passage = rate of passage of digestible NDF calculated with duodenal indigestible NDF flow

⁶ DNDF rate of digestion = rate of digestion of digestible NDF

Table 3-6 Effect of treatment on ruminal pH and volatile fatty acids

	Treatment ¹				P = ²		
	DF	DC	MF	MC	C	G	C x G
Daily mean pH	6.23	6.43	6.07	6.07	<0.01	NS	NS
pH variance	0.05	0.04	0.07	0.06	<0.01	<0.01	NS
pH range	1.47	1.54	1.89	1.49	NS	NS	NS
Hours, pH < 6.0	6.6	2.8	8.9	8.4	0.02	NS	NS
Hours, pH < 5.5	0.5	0.4	1.6	1.4	0.03	NS	NS
Area, pH < 6.0	178.40	84.13	316.00	290.40	0.03	NS	NS
Area, pH < 5.5	5.70	7.30	26.00	24.40	0.02	NS	NS
Total VFA, mM	103.9	92.0	102.8	99.1	NS	NS	NS
Acetate (A), mol/100 mol	59.0	60.6	56.6	58.7	0.11	NS	NS
Propionate (P), mol/100 mol	23.7	22.1	25.2	23.6	NS	NS	NS
A:P	2.5	2.7	2.3	2.5	NS	NS	NS
Butyrate, mol/100 mol	11.6	11.8	12.4	11.8	NS	NS	NS
IsoButyrate, mol/100 mol	1.8	1.8	1.6	1.8	NS	NS	NS
Valerate, mol/100 mol	1.8	1.9	2.1	2.0	0.06	NS	NS
Isovalerate, mol/100 mol	1.7	1.9	1.6	1.8	0.07	<0.01	NS
Formate, mol/100 mol	1.8	1.5	1.9	1.9	NS	NS	NS
Lactate, mM	0.47	0.00	0.58	0.41	NS	NS	NS
Ruminal NH ₃ N (mg/dl)	15.7	17.7	15.5	17.9	NS	<0.01	NS

¹Treatments: DF = dry fine, DC = dry coarse, MF = high moisture fine, MC = high moisture coarse.

² C = Main effect of conservation method; G = Main effect of fineness of grinding; C x G = Interaction of C and G.

Table 3-7 Effect of treatment on intake, milk yield, milk composition, body weight and body condition scores

	Treatment ¹				P = ²	
	DF	DC	MF	MC	C	G
DMI, kg/d	15.6	14.8	14.4	14.7	NS	NS
DMI/BW, %	3.5	3.4	3.2	3.3	NS	NS
Milk yield, kg/d	25.2	23.6	24.5	23.5	NS	0.02
4% FCM, kg/d	27.7	25.5	25.9	25.2	0.10	0.04
Milk fat, %	4.7	4.6	4.5	4.5	NS	NS
kg/d	1.2	1.1	1.1	1.1	NS	NS
Milk protein, %	3.03	2.96	3.03	2.96	NS	0.03
kg/d	0.76	0.70	0.74	0.70	NS	<0.01
Milk lactose, %	4.96	4.92	4.98	4.97	NS	NS
kg/d	1.23	1.18	1.23	1.18	NS	NS
SNF, %	8.7	8.59	8.73	8.64	NS	0.02
kg/d	4.84	4.50	4.73	4.51	NS	<0.01
BW, kg	481.7	469.4	484.4	472.6	NS	<0.01
BW change, kg/21d	-0.5	-12.3	2.3	-4.0	0.04	0.01
BCS	2.53	2.43	2.5	2.44	NS	NS
BCS change, /21d	-0.13	-0.09	-0.08	-0.11	NS	NS

¹Treatment: DF = dry fine, DC = dry coarse, MF = high moisture fine, MC = high moisture coarse.

² C = Main effect of conservation method; G = Main effect of fineness of grinding; C x G = Interaction of C and G.

Table 3-8 Effect of treatment on feeding behavior.

	Treatment ¹				P = ²	
	DF	DC	MF	MC	C	G
Eating:						
Meals, #/d	11.3	11.3	10.0	10.4	0.01	NS
Meal size, kg	1.57	1.31	1.78	1.69	0.08	NS
Meal length, min	26.1	28.3	27.0	27.8	NS	NS
Eating time, min/d	281	301	246	273	0.03	NS
Interval, min	92	84	94	94	NS	NS
Chews, /meal	1118	1485	1237	1390	NS	0.05
Chews, /d	12038	15551	11442	13435	NS	0.10
Chews /min	49.2	58.1	50.6	53.2	NS	NS
Rate, g/min	59.3	46.6	65.7	62.4	0.06	NS
Ruminating:						
Bouts, #/d	15.9	14.6	16.2	15.4	NS	NS
Bout length, min	30.8	31.8	29.7	29.4	NS	NS
Ruminating min /d	838	843	852	856	NS	NS
Interval, min	57.5	64.5	57.4	61.4	NS	NS
Chews, /bout	1758	1742	1727	1762	NS	NS
Chews, /d	27183	24614	26722	26763	NS	NS
Chews /min	57.9	64.5	57.4	61.4	NS	NS
Total chewing, min/d	1119	1144	1098	1129	NS	NS
Total chews, /d	39221	40165	38164	40198	NS	NS
Water intake, l/d	63.5	57.0	58.9	56.6	0.06	< 0.01

¹Treatment: DF = dry fine, DC = dry coarse, MF = high moisture fine, MC = high moisture coarse .

² C = Main effect of conservation method; G = Main effect of fineness of grinding; C x G = Interaction of C and G.

Table 3-9 Effect of treatment on N intakes and N metabolism of gastrointestinal tract of early lactating cows

	Treatment ¹				P = ²		
	DF	DC	MF	MC	C	G	C x G
N intake, g/d	427.5	401.3	389.4	406.9	NS	NS	0.05
Passage to duodenum							
Total N							
g/d	276.2	287.9	271.3	271.8	NS	NS	NS
digestibility, % of N Intake	69.4	76.5	73.9	71.5	NS	NS	<0.01
NAN ³							
g/d	271.1	281.5	265.0	265.3	NS	NS	NS
% of N Intake	68.1	74.8	72.3	69.9	NS	NS	<0.01
NANMN ⁴							
g/d	121.1	125.3	126.0	114.6	NS	NS	NS
% of NAN	45.1	44.8	47.8	43.0	NS	NS	NS
% of N Intake	31.0	33.5	34.5	30.6	NS	NS	NS
Microbial N							
g/d	150.0	156.2	139.1	150.7	NS	NS	NS
% of NAN	54.9	55.2	52.2	57.0	NS	NS	NS
g/kg of OMAD ⁵	21.7	29.4	21.2	25.4	0.10	<0.01	NS
g/kg of OMTD ⁶	15.0	19.2	14.5	17.3	NS	<0.01	NS
N digested postruminally,							
g/d	205.3	219.4	213.9	213.2	NS	NS	NS
Digestibility, % of N Intake	52.4	58.9	58.7	56.6	NS	NS	0.01
% of N passage to duodenum	74.3	76.2	78.8	78.4	<0.01	NS	NS
Total tract disappearance							
g/d	357.1	331.8	334.4	345.9	NS	NS	0.06
Apparent digestibility, % of N Intake	83.1	82.4	84.8	85.1	<0.01	NS	NS

¹Treatment: DF = dry fine, DC = dry coarse, MF = high moisture fine, MC = high moisture coarse.²C = Main effect of conservation method; G = Main effect of fineness of grinding; C x G = Interaction of C and G.³NAN = nonammonia nitrogen; ⁴NANMN = Nonammonia nonmicrobial nitrogen, ⁵OMAD = Organic matter apparently digested in the rumen; ⁶OMTD = Organic matter truly digested in the rumen

CHAPTER 4

FINAL DISCUSSION AND CONCLUSIONS

Experiments were conducted both before and after calving because DMI might affect the relative rates of passage, thereby affecting the digestibility of treatments. Stanley et al. (1993) reported that indigestible ADF passage increased across the prepartum period (before calving 61 days to before calving 6 days) and peaked just before calving. Postpartum indigestible ADF passage was slower than 6 days before calving but still was greater than 61 days before calving. Although differences were found in ruminal capacity, DMI, and indigestible ADF passage rate, there were no effects of period on whole tract DM digestibility in the two studies in this thesis. Faichney et al. (1988) observed a decreased ruminal retention time, and retention of digesta in the small intestine increased just before parturition. In addition, Colucci et al. (1982) found that retention time of digesta was shorter in the gastrointestinal tract with increasing intake of Holstein dairy cows.

In this study, diet differences between the experiment conducted before (4 months before calving) and after calving (1.5 months after calving) were forage percentage of the diet, NDF, protein and starch percent of the diets. The forage percentages in the diets for experiments conducted before and after calving were 62.2% and 48.7%, respectively, and were due to the higher energy and protein requirements for the cows after calving. NDF percentage of the diets was higher for the experiment conducted before calving in comparison to the experiment conducted after calving (31% vs. 27%), and starch percentage in the diets was lower before calving (38% vs. 41%).

DMI was almost twice as high for early lactation Holstein dairy cows compared with the pregnant heifers (14.9 kg/d vs. 7.7 kg/d). Rumen digesta weight and volume for early lactation cows were 1.42 fold higher than the pregnant heifers (63.2 kg vs. 44.4 kg, and 78.4 l vs. 52.2 l). Starch passage in the rumen was similar for both experiments conducted before and after calving, averaging 13%/h and 12%/h, respectively. Indigestible NDF passage was similar for both experiments averaging 2.2 %/h and 2.3 %/h, respectively. Rate of passage of potentially digestible NDF was also similar for the experiment conducted before and after calving (2.1%/h vs. 2.3%/h). Water passage was slightly higher for the experiment conducted after calving compared to the experiment conducted before calving (8%/h vs. 5%/h). The relative rates of passage were not as high as expected for the early lactation experiment compared to the experiment with pregnant heifers, possibly due to increased passage rate from fetal pressure in the rumen.

Faster rate of starch digestion and shorter retention time of starch in the rumen for the high moisture and finely ground treatments were found in both experiments. However, high moisture conservation reduced starch passage rate for the experiment conducted before calving only. High moisture conservation and fine grinding increased both apparent and true ruminal digestibility of OM and ruminal digestibility of starch digestion for both experiments (Figure 4-1 and Figure 4-3). The higher ruminal starch digestibility was due to faster starch digestion rate. The higher rate of digestion might be due to increased surface area available for enzymatic attack for the finely ground corn and increased solubility of endosperm protein increasing access of microbes to starch granule for the high moisture corn (Oke, et al., 1991). High moisture conservation decreased ruminal NDF digestibility only for early lactation dairy cows and a significant interaction of treatment was observed indicating that the reduction was much greater for the finely ground corn diets. This might be because high moisture conservation decreased ruminal digestibility of NDF by increasing rate of passage of indigestible NDF (OUTFLUX). Grant and Mertens (1992) reported that additional starch decreased in

vitro NDF digestibility due to a decreased rate of digestion and increased lag time, and some rumen microbes had greater preferences and affinities for some carbohydrates (glucose, maltose, and sucrose) than others (xylose and cellobiose). Fine grinding had no effect on ruminal NDF digestibility for both experiments.

Postruminal starch digestibility as a percent of starch intake was lower for high moisture and finely ground treatments for both experiments (Figure 4-1). Postruminal starch digestibility as a percentage of starch entering the duodenum was lower for high moisture corn diet and finely ground corn diet for pregnant heifers. However, high moisture treatment increased post ruminal starch digestion as a percentage of starch entering the duodenum and fine grinding had no effect on post ruminal starch digestion as a percentage of starch entering the duodenum for the experiment conducted after calving. The reason for this opposite effect of high moisture conservation on postruminal starch digestibility for the experiment conducted before and after calving is not apparent. Total tract digestibility of starch was higher for finely ground corn diet compared to coarsely ground corn for both experiments and high moisture conservation increased total tract starch digestibility for early lactation cows only.

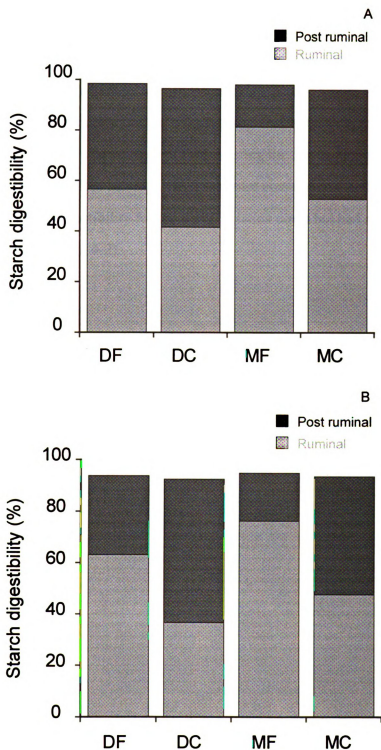


Figure 4-1 Ruminal, postruminal and total tract digestibility of starch for before calving (A) and after calving (B)

DF: dry fine, DC: dry coarse, MF: high moisture fine, MC: high moisture coarse

Fine grinding decreased postruminal OM digestibility as a percentage of OM intake and as a percentage of OM entering the duodenum in both experiments. However, high moisture conservation reduced postruminal OM digestibility as a percentage of OM intake and as a percentage of OM entering the duodenum only for the experiment conducted before calving. High moisture conservation and fine grinding increased total tract OM digestibility for the early lactation cows but had no effect on the pregnant heifers (Figure 4-2).

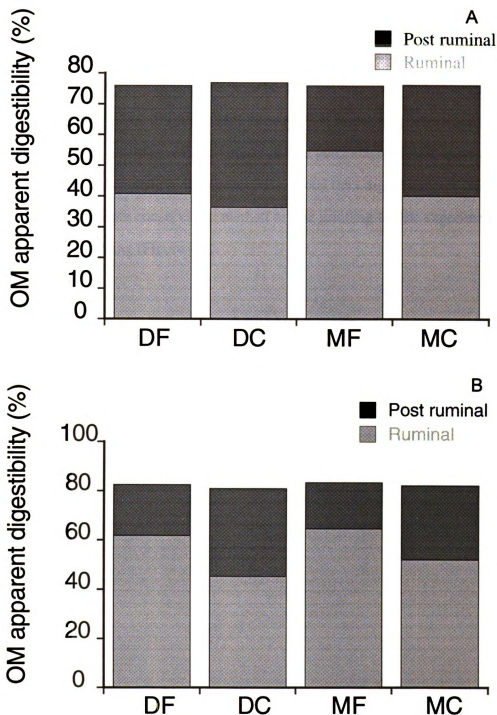


Figure 4-2 Ruminal, postruminal and total tract digestibility of OM for before calving (A) and after calving (B)

DF: dry fine, DC: dry coarse, MF: high moisture fine, MC: high moisture coarse.

Postruminal NDF digestibility as a percentage of NDF intake decreased for fine grinding for the experiment with pregnant heifers; but was not affected by fine grinding for early lactation cows. High moisture conservation increased postruminal NDF digestibility as a percentage of NDF intake or as a percentage of NDF entering the duodenum for early lactation dairy cows only. Total tract digestibility of NDF did not alter by high moisture conservation method or fine grinding for the experiment conducted before or after calving (Figure 4-3).

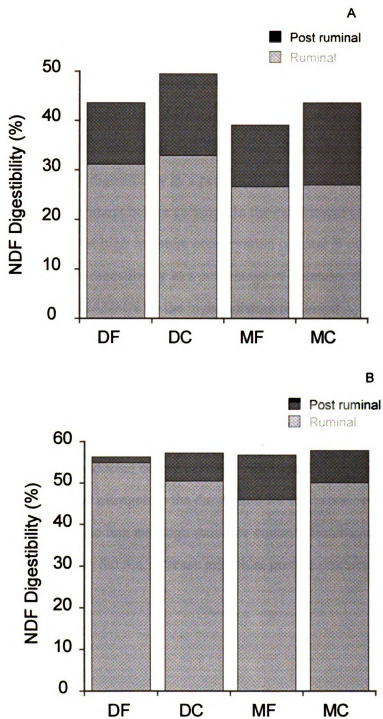


Figure 4-3 Ruminal, postruminal and total tract digestibility of NDF for before calving (A) and after calving (B)
DF: dry fine, DC: dry coarse, MF: high moisture fine, MC: high moisture coarse.

Although total tract digestibility of total N was increased by high moisture conservation for the experiment conducted after calving, total N, NAN, NANMN, microbial N passed to the duodenum and N digested postruminally tract were not affected by high moisture conservation (Figure 4-4). The increase was due to increased postruminal N digestibility as a percentage of N passage to the duodenum, which differed from the experiment before calving. In the experiment conducted before calving, there was no effect of high moisture conservation on total N digestibility, in spite of decreased postruminal N digestibility as a percentage of N intake, the passage to duodenum of total N, NAN and NANMN by the high moisture treatment.

Fine grinding decreased and high moisture conservation tended to decrease microbial protein per kg of OM apparently or truly fermented for the experiment conducted after calving. However, only high moisture conservation reduced efficiency of microbial protein production per kg of OM apparently or truly fermented for the experiment conducted before calving. Additionally, high moisture conservation reduced passage of total nitrogen to the duodenum for the experiment conducted before calving. Finally, fine grinding and high moisture conservation increased ruminal starch digestibility but did not increase microbial protein production for both experiments. (Figure 4-4).

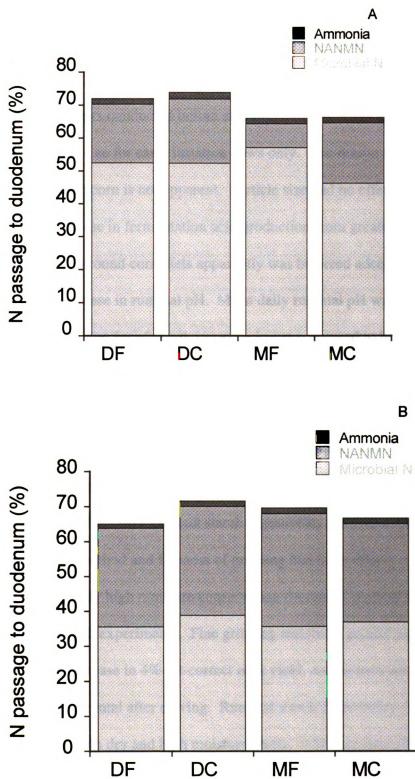


Figure 4-4 N passage to duodenum for before calving (A) and after calving (B)
 DF: dry fine, DC: dry coarse, MF: high moisture fine, MC: high moisture coarse.

High moisture corn decreased mean ruminal pH and increased variance in ruminal pH for both experiments. However, there was no effect of treatment on DMI even though high moisture conservation decreased the daily number of meals consumed for both experiments conducted before and after calving. High moisture corn tended to increase meal size for early lactation cows only. The reason of increased number of meals by dried corn is not apparent. Particle size had no effect on ruminal pH. The assumed increase in fermentation acid production from greater ruminal OM digestibility for the finely ground corn diets apparently was buffered adequately in the rumen to prevent a decrease in ruminal pH. Mean daily ruminal pH was 0.5 units lower for high moisture corn diet for after calving experiment compared to before calving experiment (Table 2-6 and Table 3-6).

In summary, high moisture conservation method and fine grinding increased ruminal digestibility of starch and OM for both experiments. The higher ruminal starch digestibility was due to faster rate of starch digestion in the rumen. Fineness of grinding had a greater effect on total tract starch digestibility for both experiments. Although both conservation method and fineness of grinding had large effects on ruminal starch digestibility only high moisture conservation decreased ruminal pH, and number of meals per day for both experiments. Fine grinding resulted a greater gain (or less loss) of BW per day, an increase in 4% fat-correct milk yield, and an increase in milk protein content for the experimental after calving. Ruminal starch digestibility can be increased by fine grinding for both dry and high moisture levels. Although fine grinding and high moisture conservation increased substrate available for microbial protein production, the fineness

of grinding and conservation method used depends upon the animals abilities to neutralize fermentation acids and maintain ruminal pH.

FUTURE WORK

Research is needed to confirm the effects of high moisture conservation method and fine grinding on ruminal starch and OM digestibility at different concentrations of starch and NDF in the diets from the same source. Future work is also needed to understand the mechanism by which dry corn resulted in an additional meal per day and why fine grinding increased ruminal and total tract starch digestibility with no effect on ruminal pH.

APPENDIX A. FORMULAS USED

% solids not fat (% SNF)

= % milk protein + % milk lactose + % milk ash

-assumed .71 % for % milk ash

Source: Tyrrell and Reid (1965) JDS 48:1215.

average % fat for test week (similar for %protein, %lactose and SCC)

= (total lb. fat produced for six sampled milkings) + (total lb. of milk produced for six sampled milkings)

= ((lb. of milk from first milking)(first milking % fat/100) + (fat lb. from second milking) + + (fat lb. from sixth milking)) + ((lb. of milk from first milking) + (lb. of milk from second milking) + + (lb. of milk from sixth milking))

4.0% FCM (source: NRC, 1989)

= milk kg (.4 + (.15)(% milk fat))

3.5% FCM (source: NRC, 1989)

= milk kg (.43 + (.162)(% milk fat))

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